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Pyrotechnic Harassment Device (PHD) (U)

by

Richard C. Grimm

Douglas P. Davis

Special Devices, Incorporated

MARCH 1966

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PYROTECHNIC HARASSMENT DEVICE (U)

(PHD)

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FOREWORD

This document was prepared for the U. S. Air Force Systems Command, Research and Technology Division, Directorate of Armament Development, Weapons Division (ATWR), Eglin Air Force Base by Special Devices, Incorporated, Newhall, California under Contract No. AF08(635)-4773 in accordance with ATL Exhibit No. 64-1, dated 28 September 1964.¹ The project engineer for DAD Project Office ATWR is Mr. Ray Vermillion. This document has been assigned Special Devices' Document No. 1444-1.

This program to meet the technical requirements of RTD, Det 4 Exhibit No. ATW 64-74 dated 30 March 1964 was accomplished by Special Devices, Incorporated, Newhall, California during the period of November 1964 to August 1965. The principle Special Devices' personnel for this effort were Mr. Douglas Davis and Mr. George Boothroy, acting under the general program direction of Mr. Richard Grimm. This document was prepared by Mr. Grimm and Mr. Davis, and was submitted 13 August 1965.

Acknowledgement is made to Mr. Ray Vermillion, Contractual Project Engineer, Eglin Air Force Base, and Mr. I. G. Broussard, Psychologist (ATWR) Eglin Air Force Base, for their valuable technical assistance and guidance.

This report contains no classified information extracted from other classified documents.

This document has been marked in accordance with the DOD Industrial Security Manual by the contractor.

This report has been reviewed and is approved for publication.


ROY C. COMPTON
Technical Director, Weapons Division

¹ Changed to Air Force Armament Laboratory, effective 1 March 1966.

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CONFIDENTIAL ABSTRACT

The PHD (Pyrotechnic Harassment Device) was developed to experimentally establish the feasibility of putting a pyrotechnic gunshot and voice sound generator, for harassment of enemy troops, in a single air-droppable unit. This effort included studying methods by which speech, screams, mechanical and animal noises could be generated synthetically with low cost pyrotechnic devices. The air-droppable prototype unit developed is suitable for delivery from the SUU-13/A dispenser. This unit can meet the general requirements of aerodynamic stability, floatation, ground orientation, self destruction after use, and a sound pressure level (spl) output of 80 db measured at a distance of 100 feet. The unit fires eight bursts of eight shots each, over a period of six hours. Associated with each burst is a scream. The eight-shot bursts are broken into two sequences of 2 shots and one sequence of 4 shots. Timing of the bursts is random, so the bursts do not repeat at equal intervals, and the 2-2-4 shot sequence does not repeat in the same order for each burst. The scream takes place anywhere in the eight-shot burst. Pure pyrotechnic synthesization of human and animal sound does not appear feasible for the purpose intended. The extreme degree of frequency and amplitude modulation required for human and animal sounds can not be realized without a complicated supporting system to control the output of the pyrotechnic generator. Simple screams can be approximated pyrotechnically, but the fidelity is poor and the sound approaches that of a whistle. White noise can be made by including a reed system in the exhaust gas stream, but this sound is neither frightening or meaningful. Good fidelity with all types of human and animal sounds was achieved with a mechanically coupled recording and speaker. However, the required spl of 80 db at 100 feet could not be achieved with a reasonably sized unit (4" x 4" x 4"). The conclusions from tests performed at the contractor's facility, and at Eglin Air Force Base were:

- o Gunshot simulation is feasible and effective with pyrotechnic simulators.
- o All other types of sound, except for pure whistles and white noise, are not suitable for generation with pyrotechnic devices.
- o The spl of 80 db at 100 feet is not required for voices and animal sounds.
- o The complex unit developed to meet the general requirements should be separated into simpler low cost elements; a unit that simulates gunshots, a unit that reproduces voice and animal sounds using the mechanical coupled record-speaker speaker principle, and a whistle unit.

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- o The single-purpose units should be designed for dispensing from a simple reloadable internal dispenser that can deliver various mixes of these single-purpose units.

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I

INTRODUCTION & SUMMARY

Special Devices, Incorporated, located at Newhall, California, has completed a 6-month program for the research, development, fabrication, and testing of a Pyrotechnic Harassment Device (PHD). This device is an air deliverable unit that generates noise over a six hour period to harass, by generally upsetting enemy troops, and thus lowering their efficiency for fighting. The PHD also could have potential as an offensive weapon. By dropping a number of units around an enemy group under attack, the PHD may cause general confusion and make it impossible to determine from exactly which direction the attack is coming, or the size of the attacking force.

This program began with an applied research effort to determine the sounds that could be reproduced with simple pyrotechnic, or mechanical-pyrotechnic devices.

It was determined that gunshots, whistles, white noise, and to some degree neutral screams, could be synthesized with gas driven rotors, vibrating air columns, and orifices. All other potentially usable sound, such as human voices and animal noises (excepting hisses, which are in effect white noise), are not possible to reproduce because the extreme amplitude or frequency modulation requires some type of programmer to control the pyrotechnic output. The development of such a controller was beyond the scope of this program, and would have rendered the PHD unit prohibitively expensive.

A mechanically coupled record and amplification system was studied as a possible method of generating the more complex sounds. A 3-inch multi-track record was cut and tested. Fidelity was good for this system, but the required spl output of 80 db at 100 feet not attainable, unless electronic amplification and large speakers are used. These additions will render the PHD unit too large and expensive. The maximum spl output realized from the mechanical system tested was 85 db at 2 feet, and the system would fit in a 3.5 diameter case approximately 4 inches long.

From the applied research effort on sound generation it was determined that the PHD unit would be made up of gunshots and scream generators, since these two sounds have a related effect.

The PHD has to be air droppable from an existing dispenser, and the SUU-13/A was chosen over other dispensers because:

- o The SUU-13/A allows a good combination of PHD unit weight, external shape, and volume.
- o The SUU-13/A downward ejection assures the PHD will clear the delivery aircraft.

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- o The SUU-13/A meets the requirement for single or multiunit ejection.

Thus, the overall shape of the PHD unit was fixed at 4.625 inches in diameter, and 10 inches long; the size which could be accommodated by a SUU-13/A ejection tube.

To achieve trajectory control, ground orientation, and floatation, a gas generator and inflatable rubber bag are located at each end of the PHD. One bag is inflated upon ejection from the SUU-13/A to drag-stabilize the unit and limit ground impact velocity to 65 feet/second. The second bag, controlled by a master programmer, is inflated approximately 1 minute after aircraft ejection. This bag raises the entire unit off the ground, or out of the water, and orients it for operation.

The programmer which runs from a six and one-half volt mercury power pack arms the unit against tampering, sequences 64 shots and 8 screams over a 6-hour period, and fires a 100 grain per foot "Pyrocord" destruct network at the end of the 6-hour operating period.

The gunshot simulators, scream simulators, gas generators used for bag inflation, and destruct network all are electrically initiated and fired from the power pack.

The programmer groups the 64 gunshots into 8 sequences of 8 shots each, and fires each sequence at 40 to 50 minute intervals over the six-hour period. The eight shots in each sequence are fired at an average rate of 500 rounds per minute, in one group of 4 and two groups of 2, and are controlled so the 4-2-2 array starts at random for each sequence. Finally, a scream is introduced randomly in each 4-2-2 shot sequence.

Ten complete prototype units were made, five for testing at the contractor's facility, and five were delivered to Eglin Air Force Base for testing.

The results of the program were:

- o A PHD unit capable of meeting all the original requirements as represented by the prototype hardware, is more complex, and in limited production would be more expensive than desirable.
- o The spl output of 80 db at 100 feet is not needed for speech and also this level imposes several limitations on the effectiveness of the harassment device, since the one feasible way determined to reproduce speech and other complex sounds can not reach this output level.
- o The scream simulators used in the prototypes are not realistic enough, and the pyrotechnic mixture used for gun shot simulation should be modified to reduce flash.

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- o The gas generator-inflation bag design is a new concept for single unit capable of trajectory control, reduction of terminal velocity, and floatation. It may have applications in other areas.
- o The PHD should be reduced to single function, low complexity units, including a multigunshot simulator that is completely nonelectric, a nonelectric pyrotechnic whistle, and a speech and complex-sound generator using mechanical amplification of recorded sound.
- o Breadboard tests of each of the single units should be performed at Eglin before prototype hardware is made.
- o Paralleling unit development, a simple internal dispenser design study should be performed. The dispenser must be capable of handling mixed loads of the different types of units, and reloadable in-flight during dispensing operations.

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II

PYROTECHNIC SOUND GENERATION STUDIES

Prior to prototype PHD development, a program to determine the feasibility of, and develop methods for pyrotechnic sound generation was performed. The program was divided in four general areas:

- o Gunshots (required for the PHD unit)
- o Human sounds (desired for the PHD unit)
- o Animal sounds (potentially applicable for the PHD unit in certain geographic areas)
- o Mechanical sounds

To establish a quantitative and qualitative reference of the sounds for attempted pyrotechnic reproduction, the following were recorded and analyzed.

- o 45 cal pistol
- o 30 cal machine gun, single shot
- o 30 cal machine gun burst
- o Male scream
- o Female scream
- o Neutral scream (male & female combination)
- o Elephant scream
- o Panther scream

These sounds are graphically displayed in Figures 1 through 8 where attenuation (db) is plotted vs frequency.

There are two basic characteristics displayed on the graphs which make one sound distinguishable from another; frequency and amplitude.

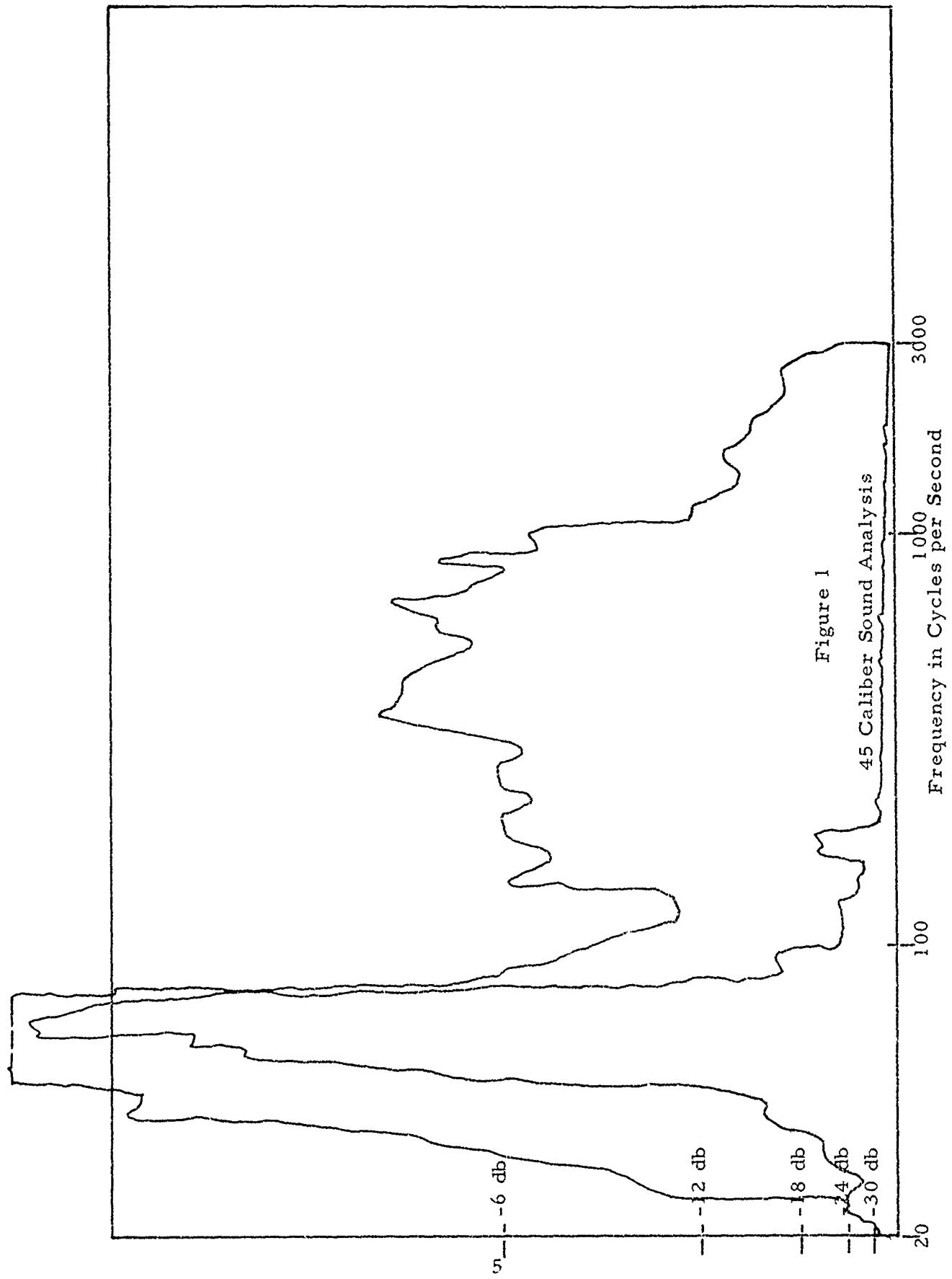
For human and animal sounds there is a very narrow db spread over any given differential frequency, and the average output changes radically with frequency. Examination of the gunshot graphs shows that their sound output is much simpler. Over any differential frequency, there is a wide db range and the average output over a wide frequency does not deviate greatly. Thus, gunshots approach white noise, while human and animal sounds are narrow band, highly modulated complex wave forms.

A. Gunshot Simulation

Various mixes of magnesium perchlorate with aluminum added to control flash were loaded into plastic containers, which were in turn held in an aluminum disc, as shown in Figure 9. The individual cartridges were fired with either 1-watt 1-amp squibs, as shown in Figure 10, or Ensign-Bickford #92-108 pyrotechnic fuze. Both methods of ignition were used because

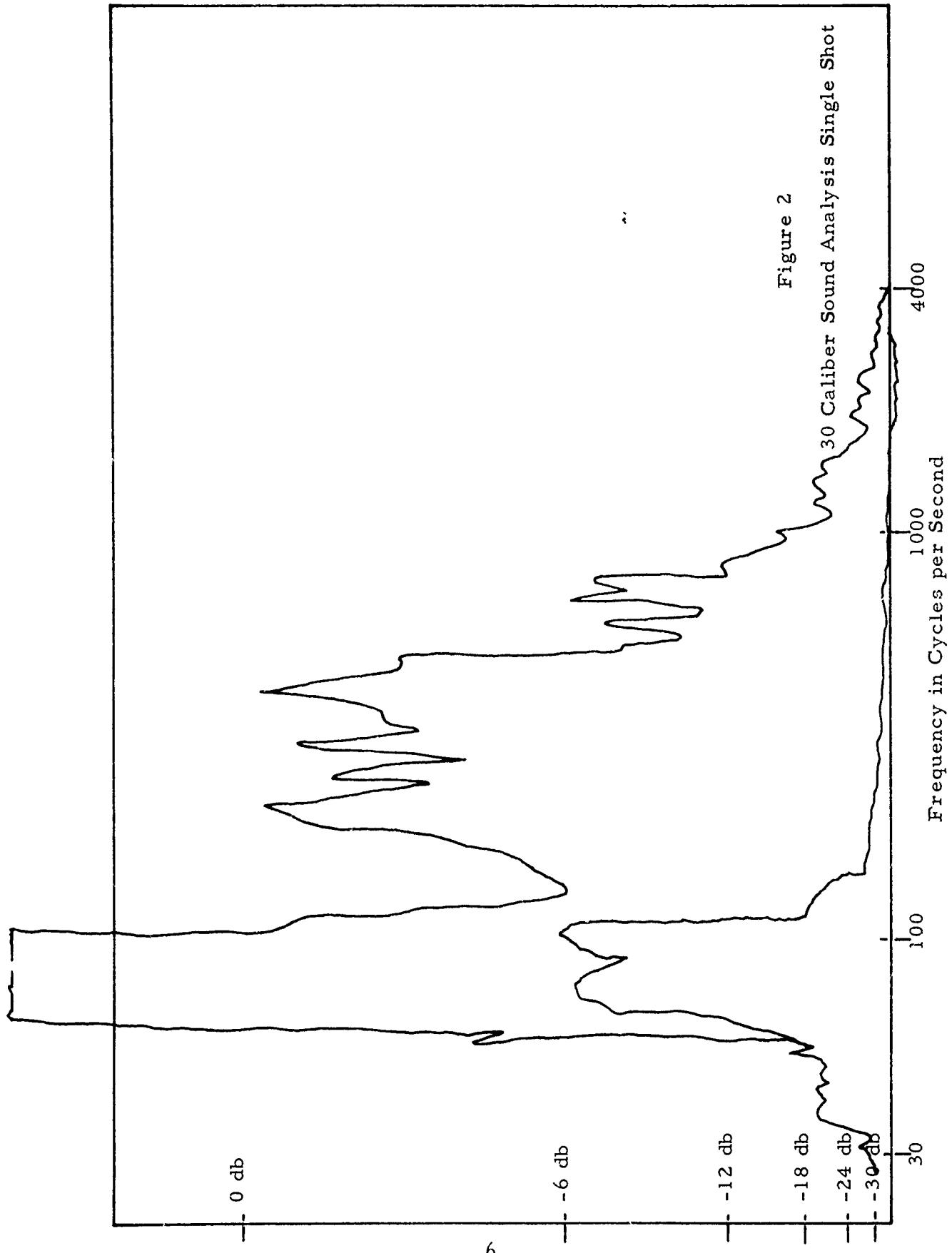
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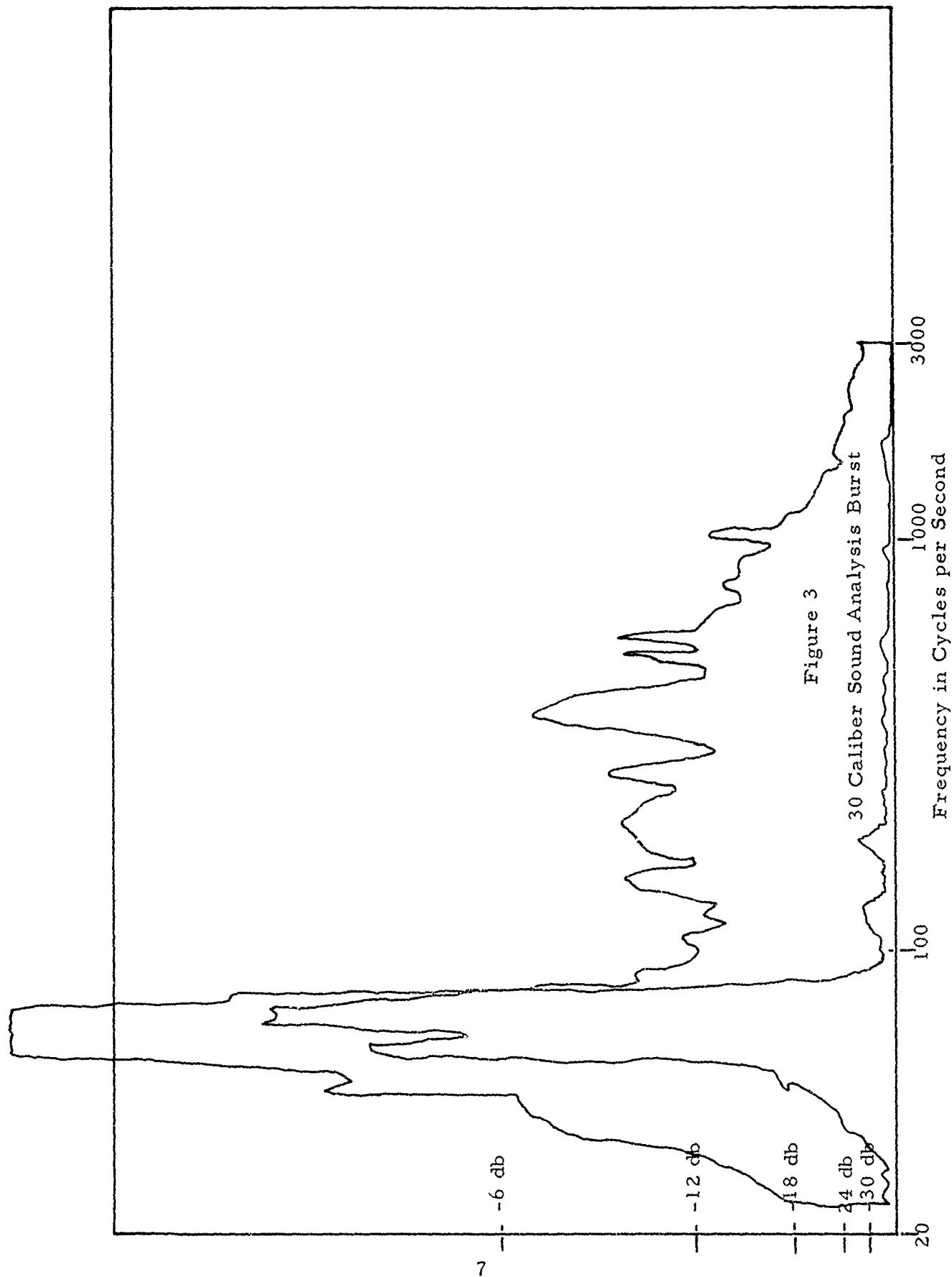


Figure 3

30 Caliber Sound Analysis Burst

Frequency in Cycles per Second

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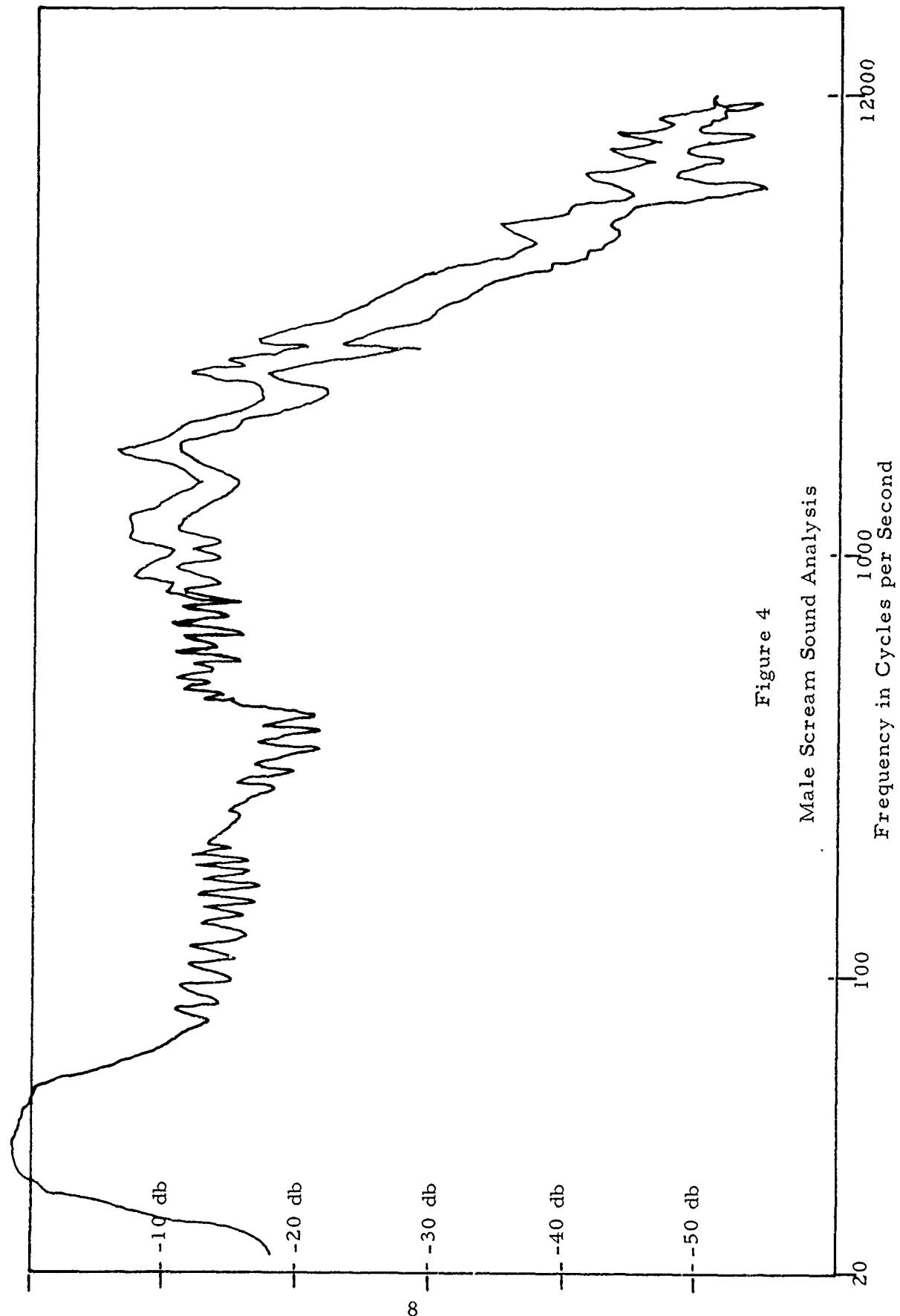
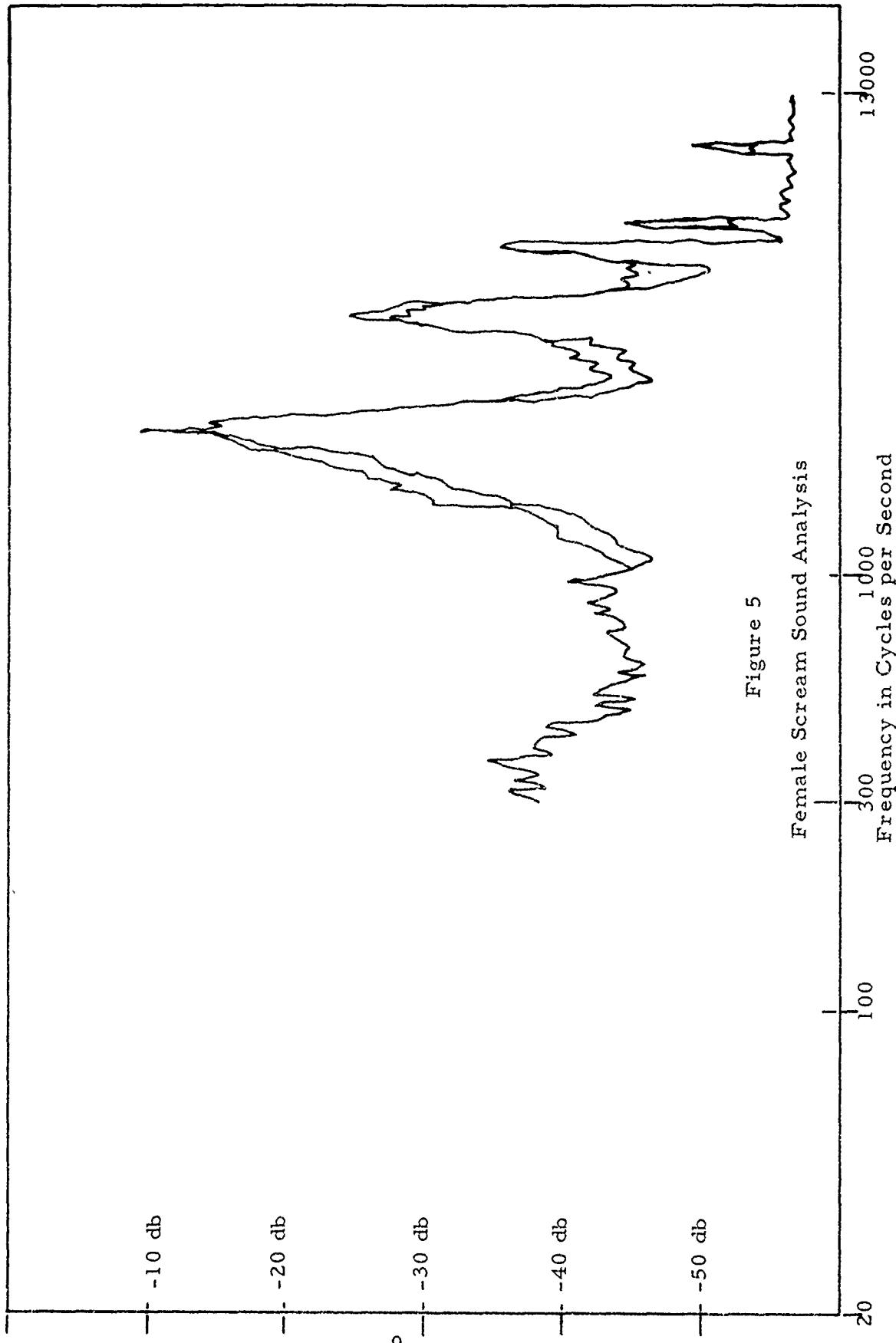


Figure 4
Male Scream Sound Analysis
Frequency in Cycles per Second

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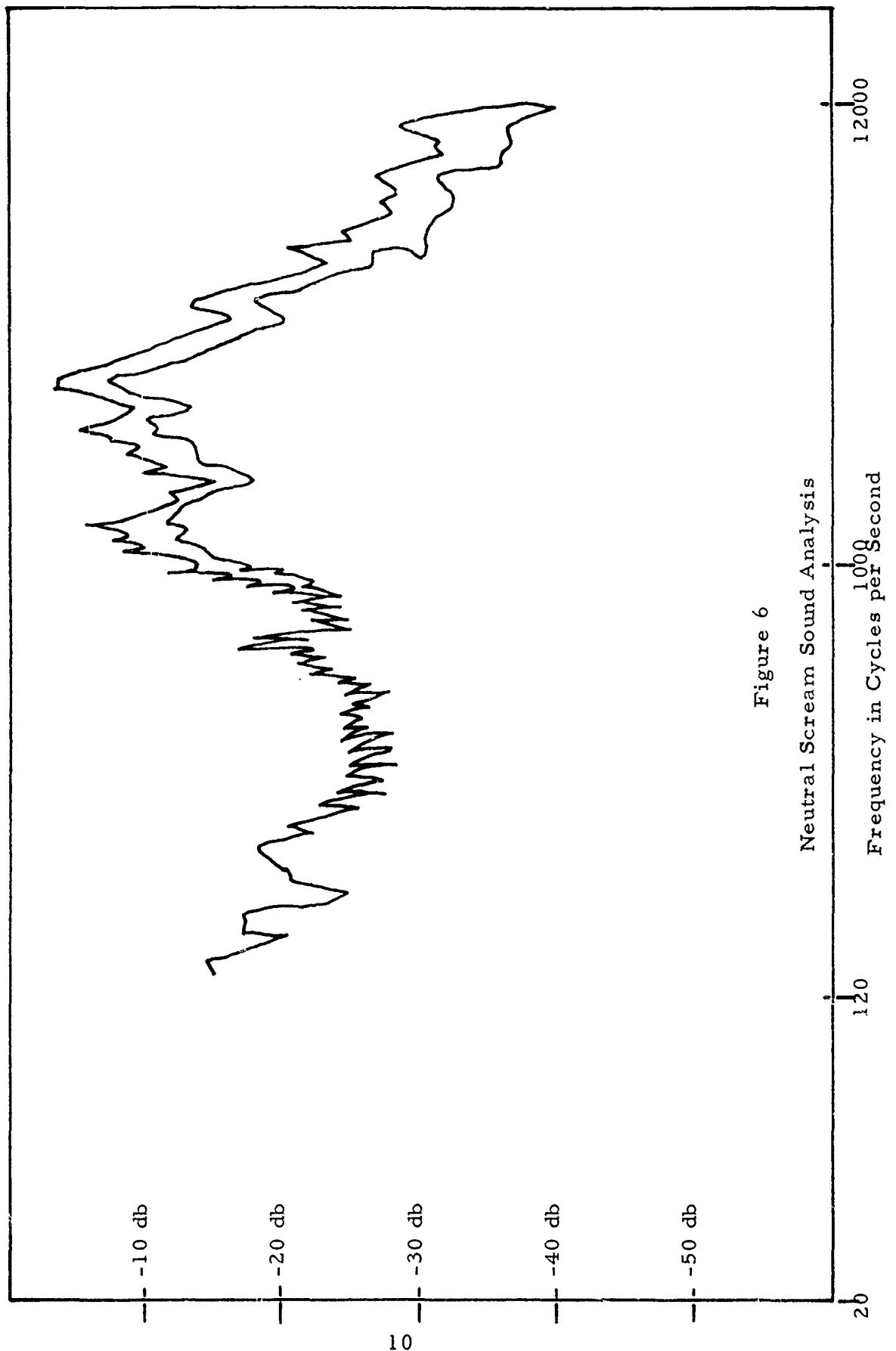
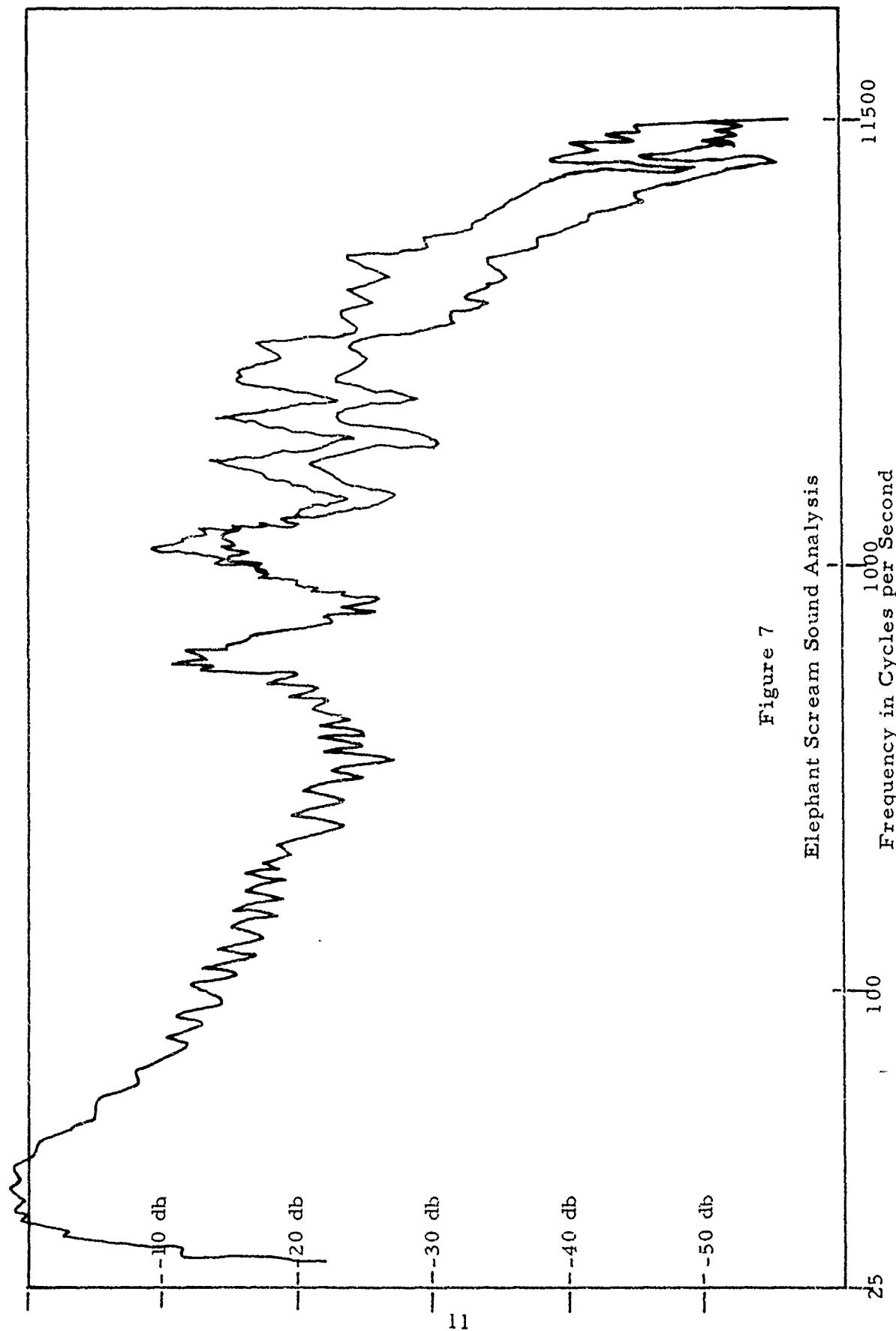


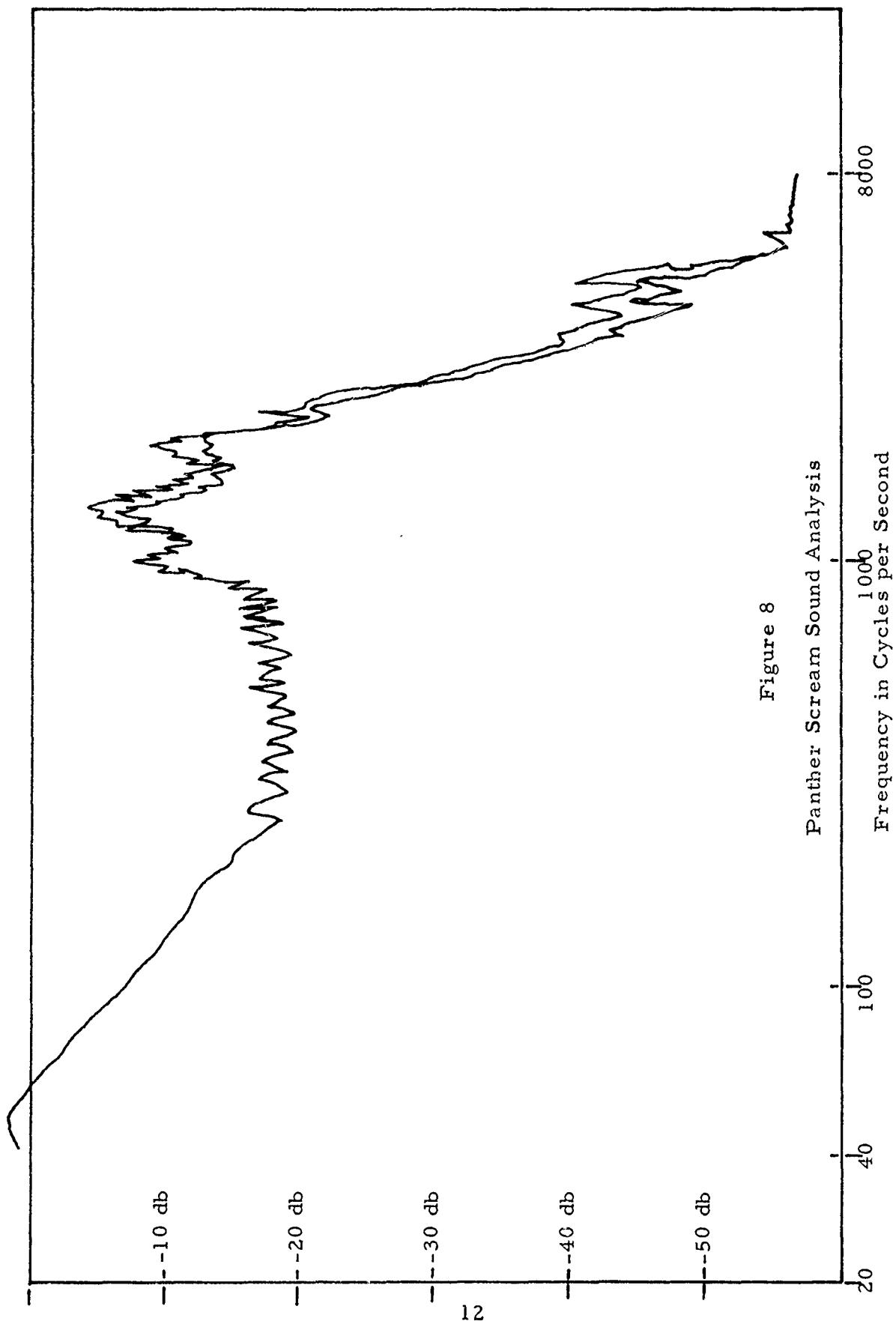
Figure 6
Neutral Scream Sound Analysis

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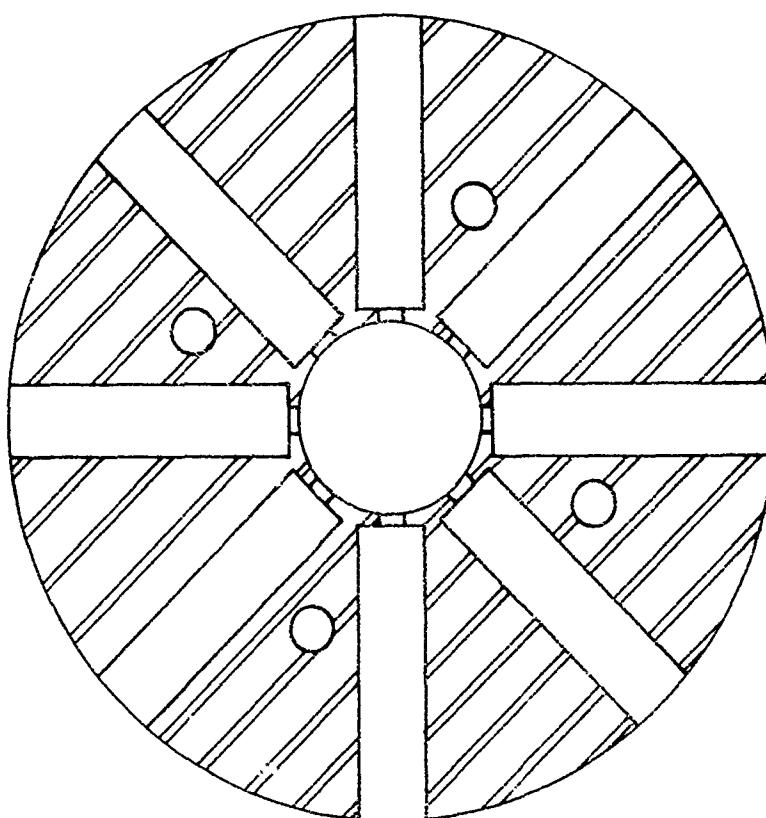


Figure 9
Aluminum Sound Generator Support Disc

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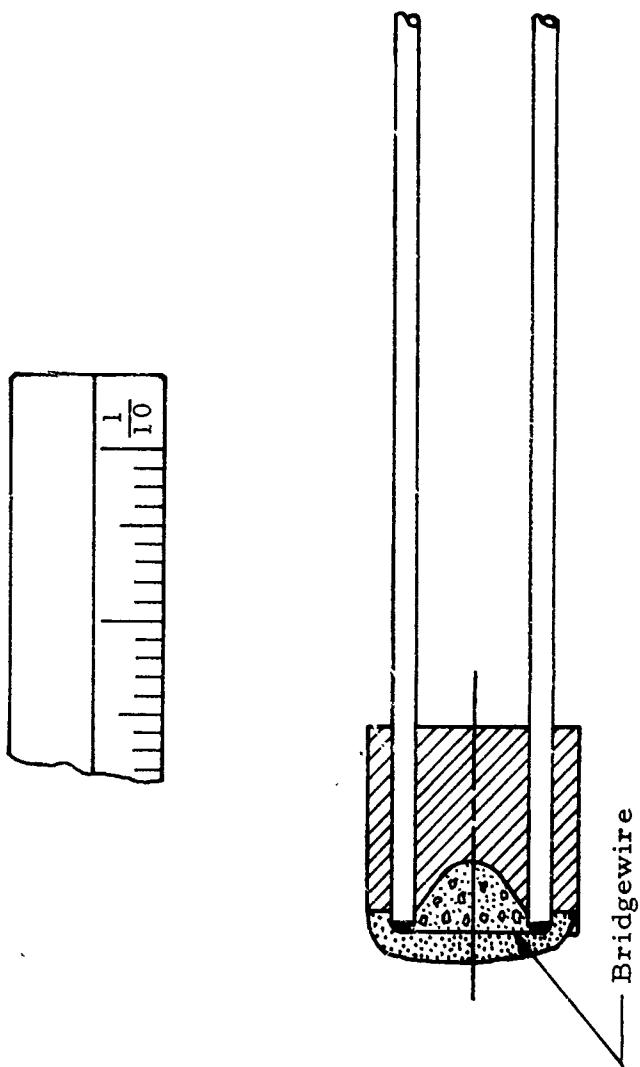
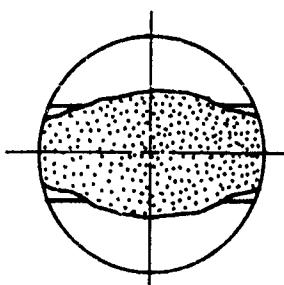


Figure 10
Z-16 Squib



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at this time in the program the actual ignition method to be used in the PHD unit had not been established. Thus, there were four basic variables in the gunshot simulation unit.

- o Pyrotechnic Mix
- o Container Size
- o Weight of Mix
- o Type of Ignition

The type of ignition (electric or pyrotechnic) proved to have no affect on the sound produced.

The general method used to evaluate the synthesized gunshots was first, to fire a 45 caliber pistol, then the simulator, and finally the 30 caliber machine gun and compare the results by ear. Simulators that passed this test were then fired with instrumentation, and a tape recording made. Then the simulator that most nearly duplicated the 30 and 45 caliber guns, as indicated by play-backs of the tape, was analyzed. The graphical representation of the final simulator is shown in Figure 11. The good correlation of the simulator with the two guns is obvious when Figure 11 is compared with Figures 1 and 2.

In all, 120 tests were made in developing the gunshot simulator. The final configuration has an internal diameter of .25 by 1.25 inches long, and contains 360 milligrams of pyrotechnic mix. The mix composition is:

51% Magnesium
4% Aluminum
45% Perchlorate

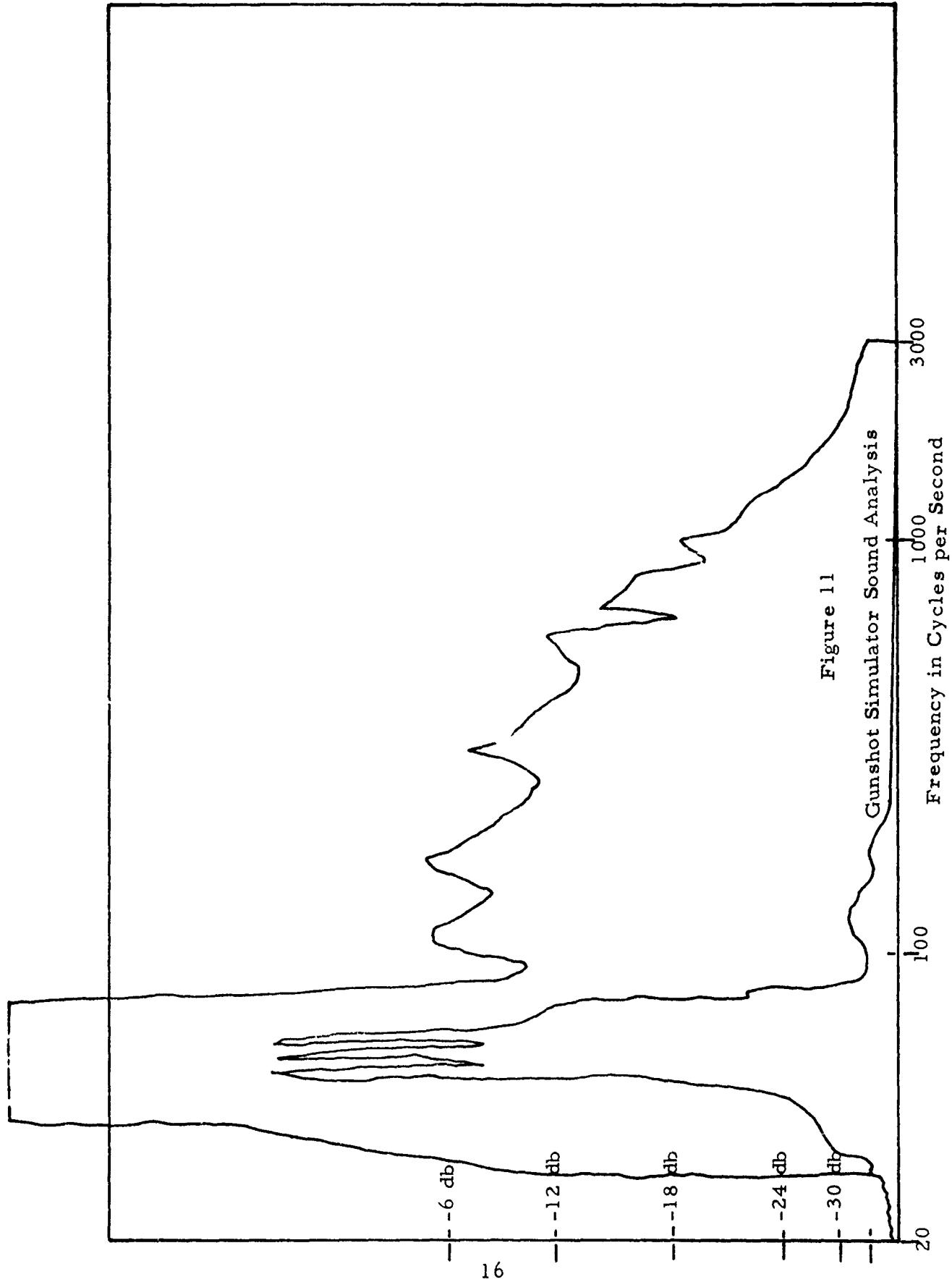
The gunshot simulator, shown in Figure 12, is made of polyethylene plastic and the sound output as displayed in Figure 11 is achieved by inserting this unit in a cavity in any ridged material that is .375 inch in diameter, by 1.25 inches long, as shown in Figure 13. The spl output versus distance for the simulator, as compared with the 45 caliber pistol and 30 caliber machine gun, is shown in Table I. The spl readings for all sound level measurements made in this program were taken with a General Radio Company 1551-C Sound Level Meter. (ref. 0.0002 microbar).

Table I
Gunshot Simulator Sound Pressure Level vs Distance

Distance from source(ft)	Simulator spl(db)	30 Cal spl(db)	45 Cal spl(db)
2.0	120	132	123
9.5	108	120	110
100.0	95	106	98

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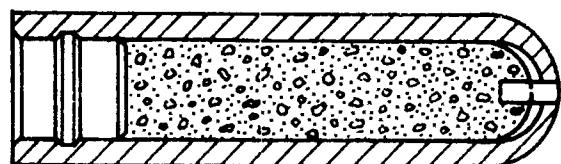


Figure 12
Gunshot Simulator Case

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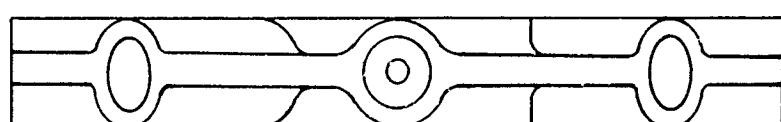
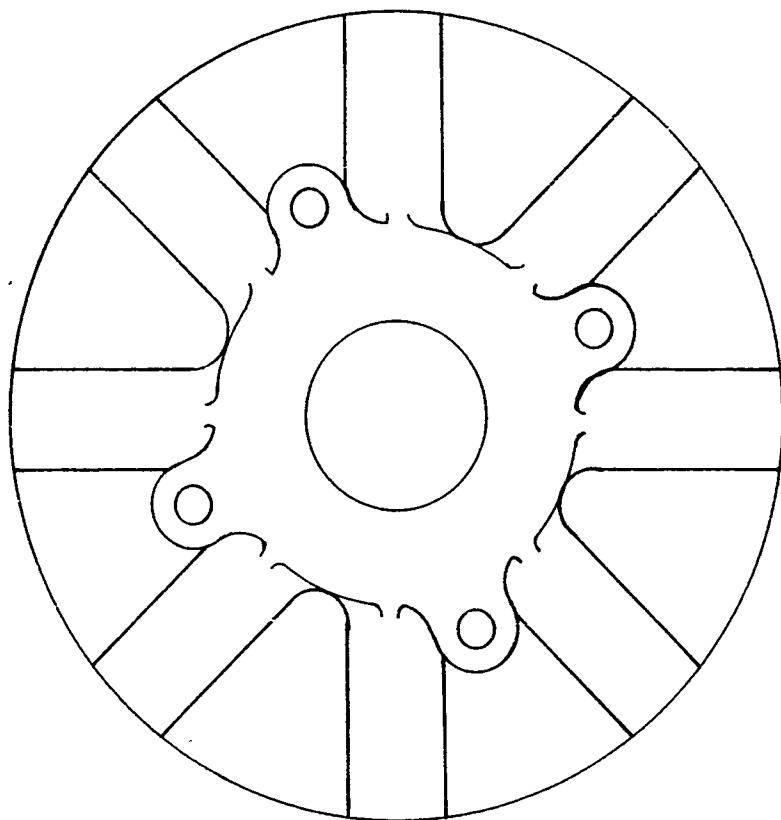


Figure 13
Plastic Sound Generator Support Disc

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B. Human & Animal Sounds

Where pyrotechnic synthesis of gunshots was basically a matter of detail refinement, because of the similar characteristics of a confined pyrotechnic mixture and a cartridge, the opposite is true for human and animal sounds. The duration and wave shape required are greatly different from that normally obtained from a pyrotechnic mixture.

To obtain the sound duration the pyrotechnic mixture must be compressed into a solid propellant with a controlled burning rate. To obtain a narrow amplitude range over a wide frequency range, the high energy gases from the burning propellant must be vented through a narrow band sound producer and modulated (valved horn for example), or a series of tuned devices (pipes for example). Further, where a gunshot is more directional, human and animal sounds tend to be generated spherically.

Assuming approximate spherical radiation of 80 db at 100 feet results in a sound intensity I of 9.3×10^{-6} watts/ft², as calculated below.

$$db = 10 \log \frac{I}{I_0}$$

$$80 = 10 \log \frac{I}{10^{-6}}$$

$$I = 10^{-8} \text{ watts/cm}^2 = 9.3 \times 10^{-6} \text{ watts/ft}^2$$

where I_0 is the reference level intensity = 10^{-16} watts/cm², and the pressure amplitude P equivalent to the calculated intensity is 4.16×10^{-3} lbs/ft².

Then the force required F at the source is the product of pressure amplitude P and the area A of the hemisphere with a 100 foot radius. This force is, $F = 262$ pounds as calculated below.

$$A = 2\pi r^2$$

$$A = 2\pi(100)^2 = 6.28 \times 10^4 \text{ ft}^2$$

and the force F is:

$$F = PA$$

$$F = (4.16 \times 10^{-3})(6.28 \times 10^4) = 262 \text{ lbs.}$$

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Assuming the average scream to be of 3 second duration, a total impulse I of 786 lb seconds is required.

$$I = Ft = 262(3)$$
$$I = 786 \text{ lb seconds}$$

where t = duration.

The higher impulse solid propellants have delivered specific impulses on the order of 220 to 250 lb-sec/lb. Therefore, to obtain spherical sound radiation approximately 3.3 pounds of propellant requiring 51 square inches of volume would be required per scream.

This is an unrealistically large amount of propellant for the PHD unit where multi-screams are required, and volume and weight allotted for each element must be a minimum.

Because of the above calculations, a series of tests were run with directional sound generating units to determine spl versus weight of propellant and pressed pyrotechnic mix. No effort was made during these tests to obtain simulated human or animal sounds. The tests were made with two types of units:

- 1) Rotary siren driven with a composite propellant gas generator grain.
- 2) Vibrating air column driven with a gallic acid pyrotechnic gas generator grain.

These units are shown in Figures 14 and 15.

After trying perchlorate, nitrate, and phenolic propellants for the siren, an ammonium nitrate rubber base propellant (Amco LFT-6) was used for the tests because its low gas temperature, and clean exhaust did not adversely affect the siren. The gallic acid pyrotechnic mix used in the standing air column whistle is a typical fireworks gas whistle.

Table II presents the average sound output resulting from 5 tests each, of the 3 propellant sizes listed, for the siren type unit.

Table II
Characteristics of Propellant Driven Siren

<u>Size/in.</u>	<u>Burn Time/sec</u>	<u>spl (db) @ 100 ft on center line</u>	<u>spl (db) @ 100 ft 50 ft off center line</u>
.375D x 1.375	2.5	84	68
.375D x 2.000	3.6	86	69
.375D x 2.625	4.8	88	70

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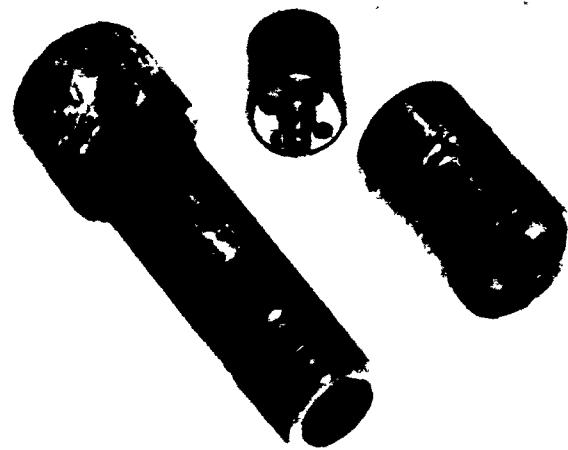


Figure 14. Rotary Siren Generator.

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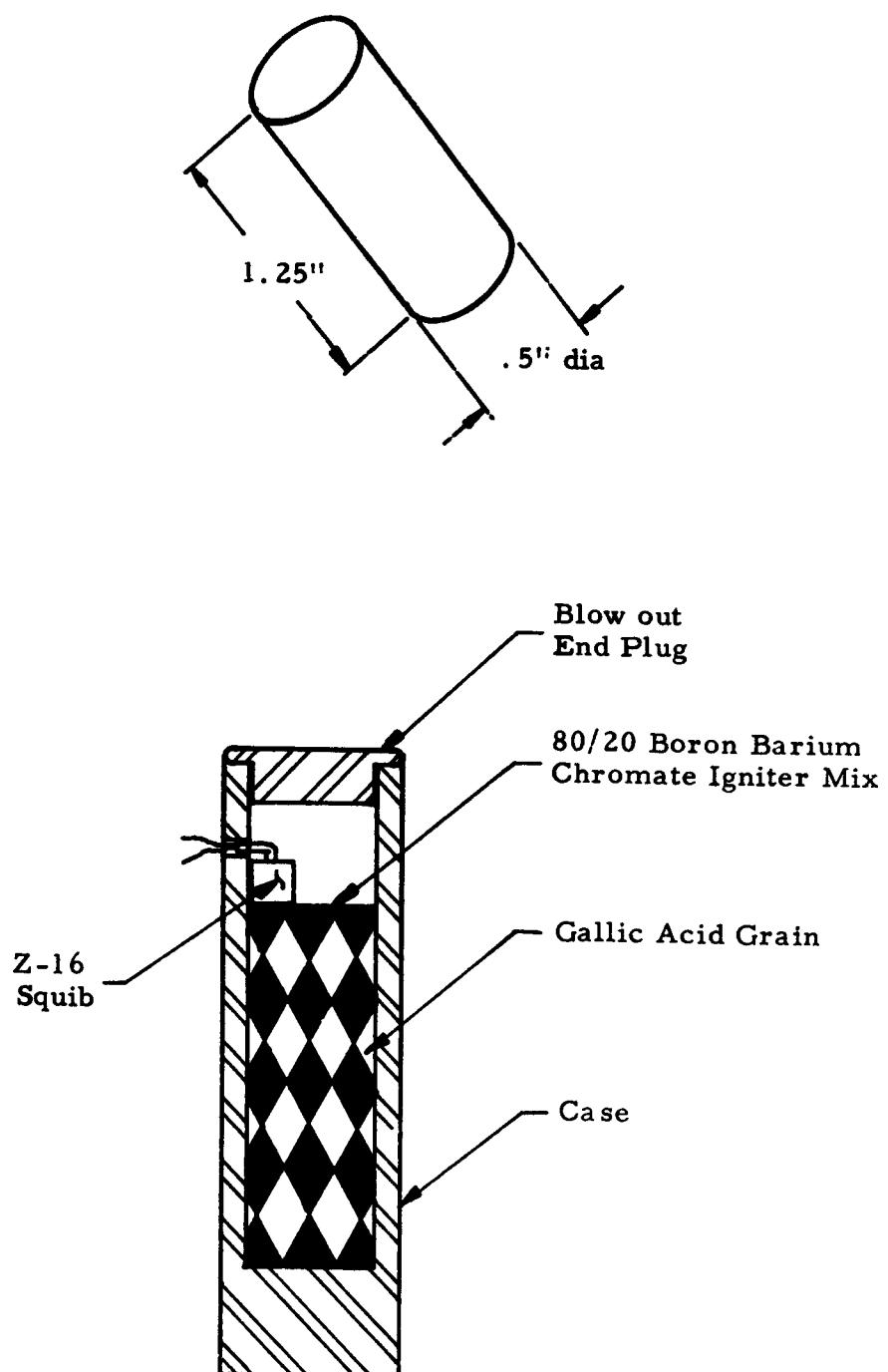


Figure 15

Pyrotechnic Whistle

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Table III presents the average sound output resulting from 2 tests each, of the 3 gallic acid grain sizes listed, for the air column whistle type unit.

Table III
Characteristics of Gallic Acid Whistle

<u>Size(in.)</u>	<u>Burn Time(sec)</u>	<u>spl(db) @ 100 ft on center line</u>	<u>spl(db) @ 100 ft 50 ft off center line</u>
.375D x 1.375	2.25	101	86
.375D x 2.000	4.40	105	88
.375D x 2.625	5.20	105	89

The composite sirens, and gallic acid whistles were both ignited with 1 amp, .86 volt Z-16 squibs, firing into 5 grains of 80/20 boron barium chromate bonded to the burning face of the grain with acetone, as shown in Figure 15. This ignition method was used in all human and animal sound simulation tests.

The siren and whistle tests demonstrated that, though directional in nature, small generators could achieve the desired output level.

A two-pronged test study was initiated. One area of study was with propellant gas generators coupled to mechanical noise generators. The other area was with pure pyrotechnic whistles.

The gas generator mechanical noise generator effort included:

- o Rotor sirens
- o Combinations of different pitch rotary sirens
- o Curved and straight organ pipes
- o Combinations of rotary sirens and organ pipes with different pitches.

In all, 18 tests were performed, as shown in Table IV, using LFT-6 gas generator grains, .375 inch in diameter by 2 inches long.

None of the units tested as listed in Table IV, had even an approximate resemblance to human or animal noise. The sound output was too mechanical or "pure".

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Table IV
Gas Generator/Mechanical Noise Generator Tests

<u>No. of Tests</u>	<u>Type</u>
2	Single rotary siren, each of different pitch
2	Double rotary siren, two different pitches
2	Triple rotary siren, three different pitches
2	Triple rotary siren, three different pitches and .5 sec delay between each siren
2	Single curved organ pipes, each of different pitch
2	Single straight organ pipes, each of different pitch
2	Double straight organ pipes, two different pitches
2	Triple straight organ pipes, three different pitches
2	Triple straight organ pipes, three different pitches and .5 sec delay between each

The pyrotechnic whistle studies included gallic acid, and picric acid pressed pyrotechnic mixes, in .2 to .5 inch diameter resonator tubes. Various references in the bibliography mentioned that there were numerous pyrotechnic whistle mixes, but an exhaustive literature search did not establish their identity. In fact, the reference material available in the general area of fireworks is very limited. Therefore, the pyrotechnic whistle studies centered around the two whistle mixes known to SDI, gallic and picric acid. Discussions with local fireworks manufactures brought forth the fact that the only whistle mixes in use today were gallic and picric acid. It was the general concensus of opinion that the numerous pyrotechnic mixes mentioned in the literature were slight modifications of the picric and gallic acid whistle mixes.

Preliminary tests were made to compare the output characteristics of the picric acid whistles versus gallic acid whistles. Four of each type were made with the following characteristics.

- o Grain size - .5" dia x 1" long
- o Tube length - 2"

No discernable difference was evidenced in the sound characteristics, and the output spl was also the same for both whistles. The picric acid

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whistle was eliminated from further testing, because the gallic acid mixture is less shock sensitive and the more stable of the two whistle compositions.

The gallic acid whistle displayed more of a basic similarity to screams than any of the mechanical-gas generator units tested. A series of tests with different unit sizes and dimensions was performed, in an attempt to simulate the frequency and sbl characteristics of the analyzed screams shown in Figures 4 through 8. In all, 35 tests were made with grain diameters varying from .18 to .70 inch, tube length variations from 1.0 to 2.5 inches, and compaction densities of .05 to .07 pounds per cubic inch. One fairly close simulation was achieved during these tests, and that was with the female scream shown in Figure 5. A gallic acid whistle with a .375 inch diameter by .6 inch long, with a compaction density of .06 pounds per cubic inch, in a 1.75 inch tube produced the sound shown in Figure 16. By comparing Figures 5 and 16, the close relationship between the fundamentals and first harmonics is evident. Also, the upper modulation and frequency relationship coincide remarkably well. However, the greater amplitude spread over a given differential frequency is apparent in Figure 16 (which all the tests in this program have shown is normal for pyrotechnics), and the absence of harmonics definitely limits the fidelity of the pyrotechnic simulator. Even with the wide amplitude spread and the lack of harmonics, the overall sound from this specific gallic acid whistle was similar to the female scream, and much better than the output from any of the other units tested.

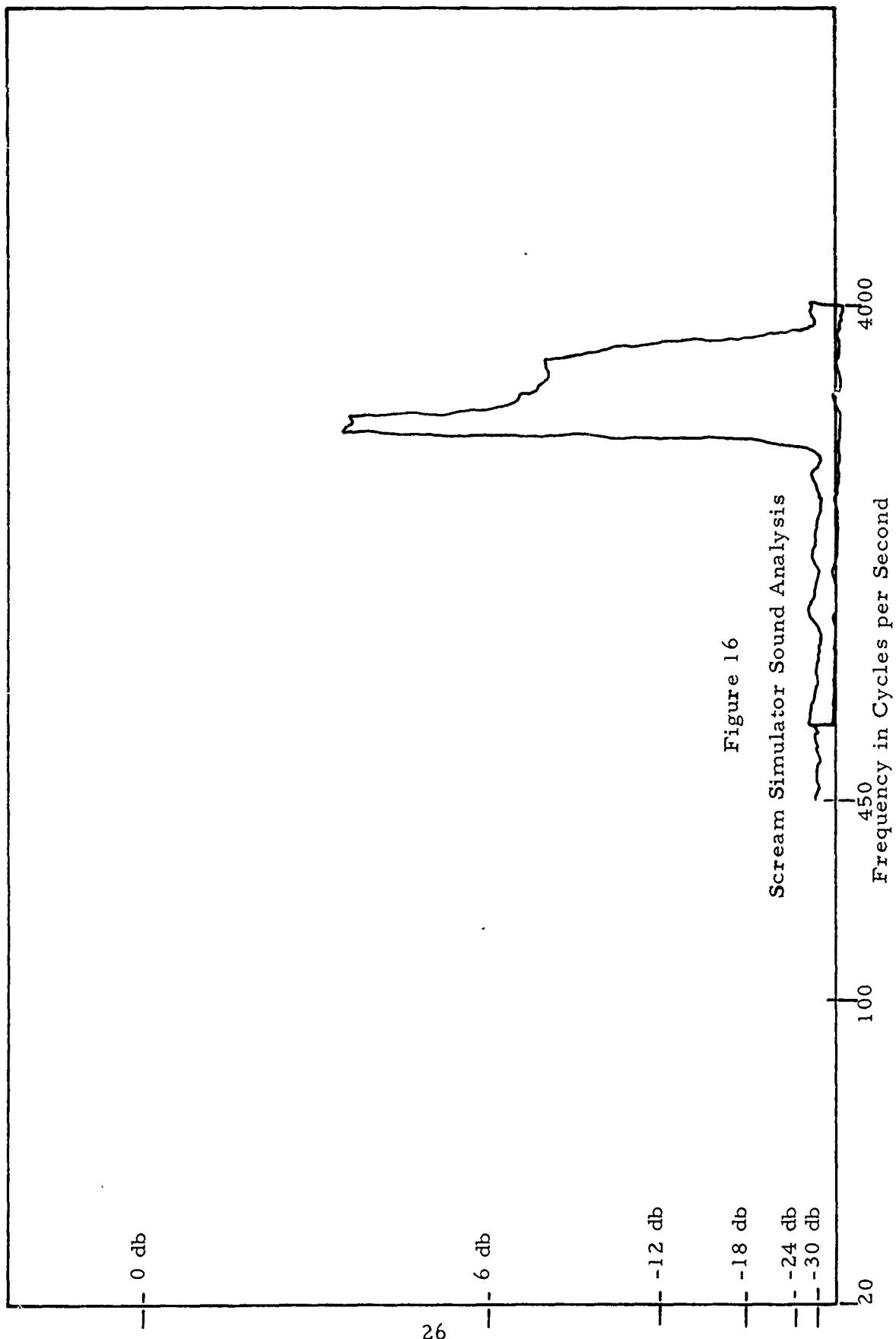
The unit that simulated female screams had the following composition and characteristics:

- o 26% Gallic Acid
- o 74% Potassium Chloride
- o .06 lbs/in³ compaction density
- o .375 inch dia x .65 inch long grain
- o .375 ID x 1.25 inch long resonator tube
- o 3.2 sec average burn time (average for 5 firings)
- o spl of 105 db @ 100 ft on center line of whistle (average for 5 firings)
- o spl of 86 db @ 100 ft, 50 ft off center line of whistle (average for 5 firings)

This unit was the 22nd tested in the series of 35 tests.

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C. Mechanical Sound Simulation Studies

Four different setups were made and tested to examine sounds that did not fall in the gunshot or human and animal scream category. They were:

- o A rotating disc with holes passing in front of the gas exit of a gas generator, and a whistle mix.
- o Vibrating reeds in the exit stream of a gas generator.
- o A 45 degree reducing orifice, and a gas generator
- o A 90 degree reducing orifice, and a gas generator

These four setups are shown schematically in Figure 17, and the gas generator is the LFT-6 unit discussed in the preceding section.

By changing the hole pattern size and rotation rate a variety of intermittent to continuous, and variable pitch sounds were achieved with the rotating disc. However, they were generally just noise, and considering the complexity of the device it was not considered applicable for the PHD unit.

The vibrating reed concept produced a composite sound that was made up of the individual frequencies of the reed, but because of the allowable unit size the sound output was very low; under 50 db spl at 2 feet.

The reducing orifices produced a hissing type sound and it is probable that with the proper orifice diameter and angle, sounds ranging from snake hisses to steam and air escaping can be produced in this manner.

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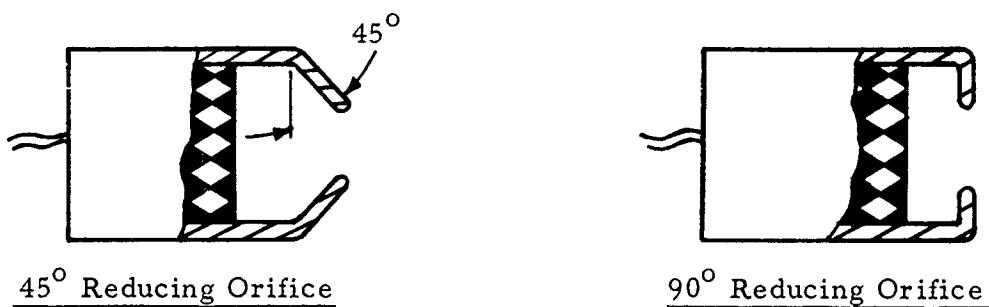
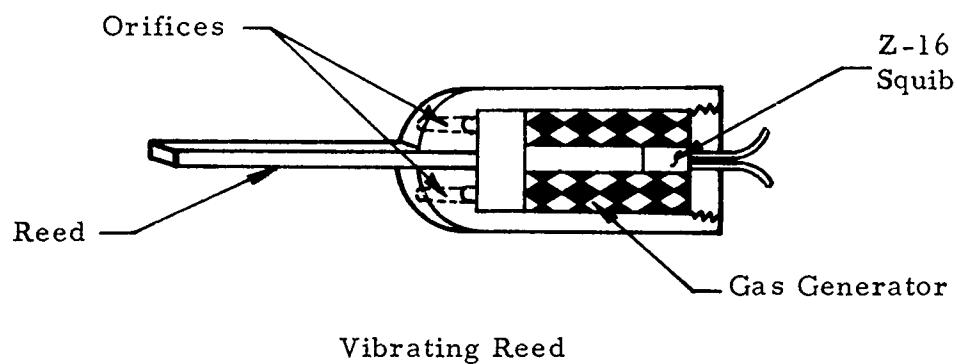
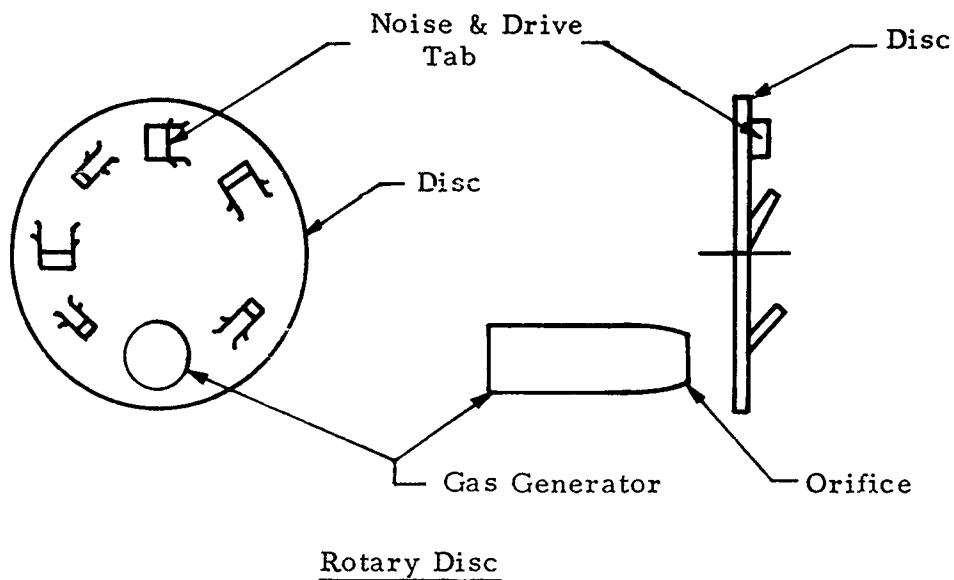


Figure 17

Mechanical Noise Simulators

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III

NONPYROTECHNIC SOUND GENERATION STUDIES

During the development of the PHD, after the basic components were established, the applicability of a small recorder and mechanical speaker system was studied. This study was undertaken as a last effort to include more effective human sounds in the harassment device. The 10 rpm motor in the control unit (discussed in Section V - A) of the PHD could be used to turn a record, and the output mechanically coupled to a speaker diaphragm at the bottom of the unit. Intermittent operation of the recorder could be achieved without increased complexity of the control system, and the entire phonograph unit included in the harassment device, at the expense of only 8 to 10 pyrotechnic sound generators.

A 3 inch vertical groove record was cut with a 3 second male scream, a 3 second panther scream, and miscellaneous talk and yells. A simple mechanical linkage from a sound pickup needle to a 3 inch speaker cone was made. The output of this unit was 70 db of spl at 2 feet. Two more records were cut at higher recording speeds. The three recording speeds used were 10 rpm, 20 rpm, and 30 rpm. The mechanical system was refined by using the maximum possible ratio of needle movement to speaker movement, without the addition of dampers to maintain needle-record contact. The maximum spl output attained was 85 db at 2 feet, and it is estimated that with further refinement, outputs of 95 db with good fidelity could be realized in the allowable envelope size. However, this is still well below the required spl of 80 db at 100 feet, so further effort was stopped.

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IV

DISPENSER

A contractual requirement precluded PHD design until a dispenser for the unit was established. This requirement was:

- o A PHD unit must be compatible with an existing Air Force dispenser system capable of single and multiple unit release.

This requirement limited dispenser choice to the SUU-13/A because it is capable of single or multiple unit release, plus the individual SUU-13/A ejection tube allows a reasonable volume, and external shape for the PHD unit.

Thus the PHD unit size and envelope is fixed by the SUU-13/A ejection tubes at 167 cubic inches, with a diameter of 4.6 inches, and a length of 10 inches.

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V

PYROTECHNIC HARASSMENT DEVICE (PHD) DEVELOPMENT

Figure 18 shows the prototype PHD unit. These units are 17 inches long and weigh 8.2 pounds. The length can be reduced by 7 inches. The sound generator column can be reduced by 4.5 inches by molding it in a single piece. Each floatation/orientation unit can be reduced in length by 1/25 inches by more tightly packing the rubber bladders and reducing plate thickness. Thus, the unit can meet the 10 inch length dictated by the SUU-13/A ejection tube. These changes were not incorporated in the prototype because they would not affect basic unit functioning for demonstration characteristics. The PHD unit contains four basic sub-systems.

- Pyrotechnic sound generating system consisting of 64 gunshot simulators, and 8 scream simulators.
- Orientation and floatation system consisting of 2 rubber bladders with associated solid grain gas generators for bladder inflation. This unit drag stabilizes and controls impact velocity of the PHD by inflating one bladder upon ejection from the dispenser. After ground impact, the second bladder inflates orienting the pyrotechnic generator above the ground.
- Destruct system consisting of a network of 100 grain per foot Primacord, which destroys the unit after completion of sound simulation.
- Control system consisting of programmer, power pack and igniter network. This system controls bladder, sound generator ignition, destruct system ignition, and timing of all functions.

The PHD unit functions as follows: Upon ejection from the dispenser, the pressure generated by the SUU-13/A ejection charge shears the four pins holding the unit in the SUU-13/A tube, and closes the arming circuit in the unit as shown in Figure 19.

- The circuit is closed to the programmer from the power pack. A direct circuit is made between the upper gas generator igniter and the power pack.
- The upper bladder is inflated, drag stabilizing the PHD and limiting the terminal velocity to 64 feet per second.

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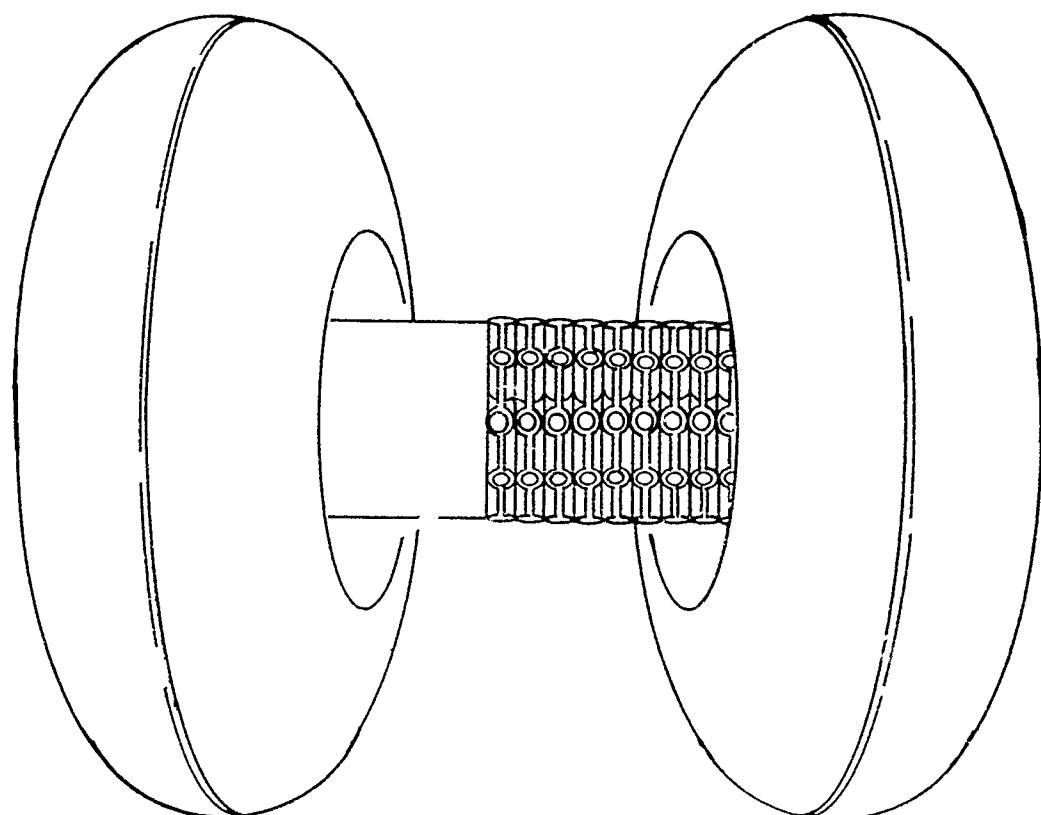


Figure 18

PHD Unit

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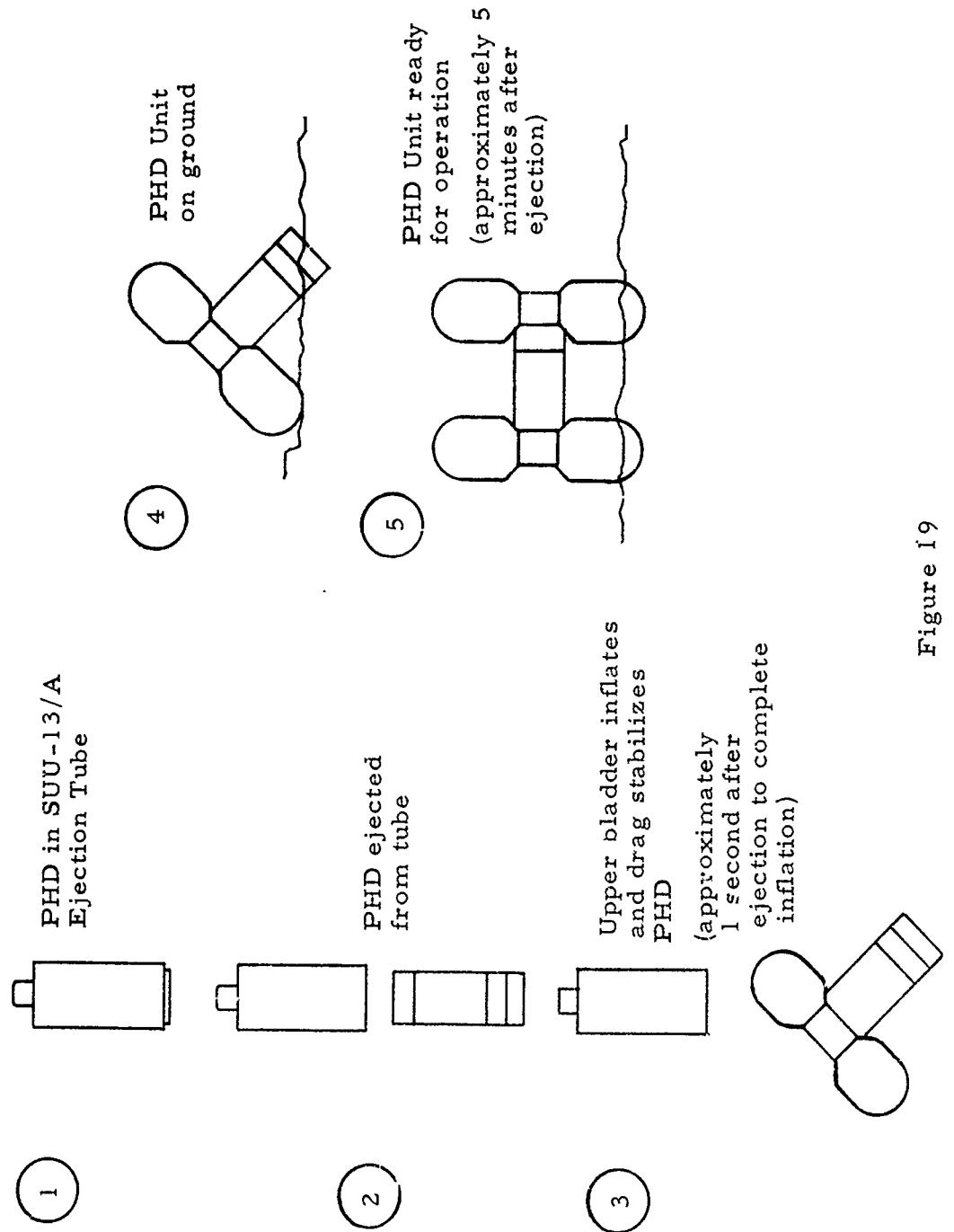


Figure 19
Ejection Sequence

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- o After the unit has reached the ground, the programmer fires the lower gas generator and the lower bladder is inflated (the programmer delays the inflation of the lower gas generator 1 minute, with time 0 beginning at ejection from the SUU-13/A.)
- o The lower bladder raises the PHD unit body off the ground or out of the water. (The body of the unit is supported above the ground or water by the inflated bladder at each end of the PHD.)
- o Approximately 10 minutes after time 0, the first series of eight shots and one scream is initiated by the programmer. The seven remaining series of eight shots and one scream are initiated by the programmer, over the following six hour period.
- o After the final series of sounds, the programmer closes the circuit between the power pack and the destruct system, and the expended PHD is destroyed.

A. Sound Simulation and Control System

Based on the results of the simulation studies presented in sections II and III of this report, the decision was made to incorporate gunshots and screams in the PHD unit. Preliminary design layouts indicated a maximum of 72, .375 inch diameter, simulators could be incorporated in the unit.

Various possible combinations of gunshot-scream relations were considered. For the prototype PHD, eight groups of 8 shots and 1 scream were chosen to function over a 6 hour period. Thus, a delay time of 45 minutes between each group firing was required. The 45 minute delay time insured an individual PHD would be difficult to locate, and allowed a variation in silence periods from 0 to 45 minutes, depending on the number of PHD's deployed in an area.

Six types of controls systems to sequence the simulators were considered.

- o Pyrotechnic
- o Mechanical
- o Electrical
- o Electropyrotechnic
- o Electromechanical
- o Mechanical pyrotechnic

It was necessary to establish the control system before the simulator system could be designed, because the control system dictates the method of simulator initiation.

Preliminary calculations indicated the pyrotechnic controller not feasible, because pressed delay columns equivalent to 1000 inches in

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length are required to achieve 6 hours of operation, as shown below.

$$D_T = t(3600) = 21,600 \text{ seconds}$$

$$D_L = \frac{D_T}{D_r} = \frac{21,000}{20} = 1080 \text{ inches}$$

where:

D_T = total delay time required in seconds

t = operating duration of PHD = 6 hours

3600 = conversion factor from hours to seconds

D_L = delay column length in inches

D_r = delay rate = approximately 20 sec/inch max.
for reliability

The delay columns would require a total volume of 196 cubic inches, allowing .25 inch diameter for the delay unit and spacing, while only 160 cubic inches are available for the entire PHD unit.

Preliminary design studies indicated a mechanical controller was not feasible because of the complexity of an entirely mechanical system, where 72 sound generators must be initiated with spring loaded firing pins.

Preliminary design studies indicated mechanical or electrical timers were feasible if the sound generators were initiated electrically. Then a slow clock mechanism could be used to achieve the 45 minute delay between each 8-gunshot and 1-scream group, while a high speed unit fired the groups. Firing circuit continuity to the simulators with this approach is achieved by rotary contacts as shown in Figure 20.

A combination electrical-pyrotechnic or mechanical-pyrotechnic control system was also potentially feasible. With this approach, the 45 minute delay between groups was controlled by a clock mechanism while the short delay between shots in a single group was controlled pyrotechnically.

Thus, four control methods were potentially feasible after preliminary design studies:

- o Electro-mechanical
- o Completely electric
- o Electro-pyrotechnic
- o Mechanical-pyrotechnic

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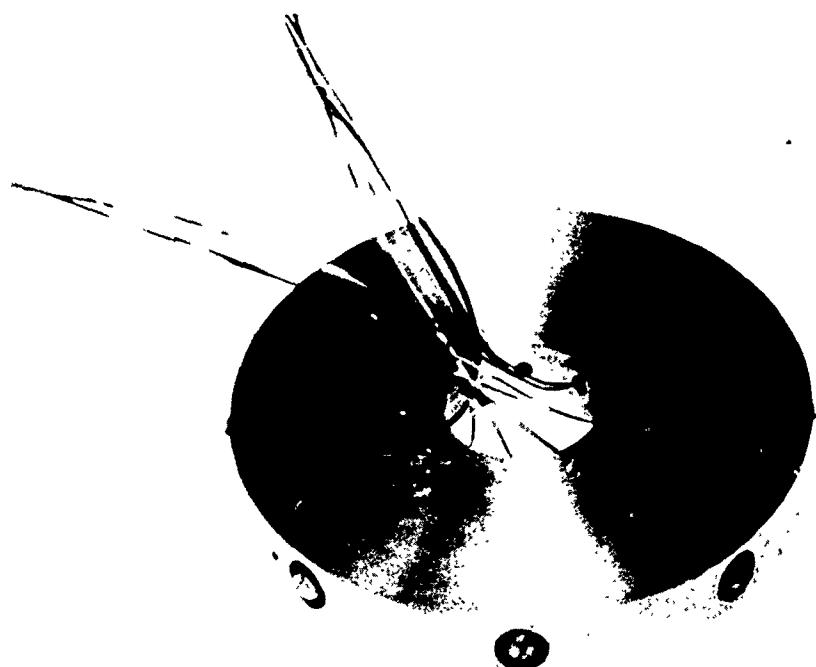


Figure 20. Timer Circuit Boards.

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Paralleling test programs were instigated to determine whether pyrotechnic delay and initiation of the 8-gunshot and 1-scream groups were superior to electrical initiation and a clock type timer.

For the pyrotechnic design to be feasible, reliable fuze train functioning and delay are required. Six fuze types were tested, as shown in Table V.

Table V

Pyrotechnic Delay Fuze Characteristics

Type	Burning Characteristics	Burning Rate
Thermalite A	Air	7.5 sec/ft
Thermalite B	Air	16.0 sec/ft
Common dynamite	Air	7.5 sec/inch
Red Vosco No. 2	Air	3.0 sec/inch
Ensign Bickford #92-108	Confined	1.71 sec/inch
Ensign Bickford #92-189	Confined	0.798 sec/inch

To test the fuze, aluminum discs with 8 chambers to receive the simulators were fabricated, as shown in Figure 21. Note the simulators shown in this figure have electric Z-16 squibs that were not included in pyrotechnic fuze train test units. Again referring to Figure 21, small transfer holes to carry the flash from the fuze to the caps in the simulators can be seen on the central hole in the discs. Figure 22 shows the fuze in place for testing before the confinement block is placed in the central hole. The confinement block is required to simulate the sealed PHD unit. Figure 23 shows a disc with the confinement block partially removed after testing.

Performance of the first 4 fuzes listed in Table V was uniformly bad, because the degree of confinement required increased their burning rates greatly, and in an uncontrollable fashion. This characteristic is typical of all air burning fuzes, but SDI believed the tests were necessary because the degree of confinement was marginal.

The last 2 fuzes in Table V are confined burning types. They are incased in a lead sheath which melts as the fuze burns. These 2 fuzes were not successful because of poor reliability with respect to simulator initiation. At each simulator location the lead sheath had to be broken to facilitate flash-over from the fuze to the ignition mix in the transfer hole. The melting lead sheath would flow into the broken area and contain the cross-flash, in approximately 50% of the tests, regardless of the method by which the break was formed or the precautions taken to contain the lead flow.

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Figure 21. Aluminum Disc and Components.

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Figure 22. Aluminum Disc with Pyrotechnic Fuze in Place.

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Figure 23. Aluminum Disc with Confinement Block in Place.

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The paralleling studies with electrical initiation were very successful. Figure 21 shows the components before assembly, Figure 24 shows the unit assembled for test, and Figure 25 shows the unit attached to the sequencing timer, ready for testing.

The average firing rate for the simulators was determined to be 500 rounds per minute, which is in the general range of most automatic infantry weapons. The 8 shots were divided into two bursts of 2 shots each and one burst of 4 shots, as can be seen by the location of the contact points on the sequencing timer in Figure 25.

Thus, the electrical initiation and clock timer proved to be far superior to pyrotechnic delay and initiation for the firing of the 8-gunshot and 1-scream groups. Since this established the requirement for batteries and an electrical system in the PHD unit, the slow speed timer could also use this power supply for operation and the design effort was concentrated on a completely electric control system. The adoption of an electrical control system for simulator control allowed the design of a completely integrated control system, because all PHD functions including:

- 1) Drag Stabilizer and floatation bag inflation
- 2) PHD unit arming (booby trap)
- 3) Sound simulation generation
- 4) Unit destruction

can be timed and functioned with the slow speed timer and associated circuitry.

Two gearhead DC motors (Cramer, type 2220) were used for the PHD prototypes. This motor type was chosen for its low power requirement (.039 amps at 6 volts), compact size (1.8" dia x 1.4" high), and rugged construction. The high speed timer configuration of the motor used to function the 8-gunshot and 1-scream group was designed for a speed of 10 rpm to obtain the 500 round/minute fire rate. The slow speed timer configuration of the motor used for total PHD unit control was designed for one revolution per hour. Thus, the prototype units completed all their functions in one hour. This modification was made for test purposes. In a field unit, the 1 rph motor would be replaced by a 1/6 rph motor to obtain the required 6-hour function cycle.

Mallory No. M-1348R mercury cells were used for power. The individual cell has a power rating of 2500 milliamperes and 1.34 volts. Five of these cells in series make up the power pack. Subsequent bench testing proved a single power pack capable of functioning at least 4 PHD units. These tests were made with the setup shown in Figure 26, where the battery pack and timer are contained in the case marked "10". The central stack contains 64 gunshot simulator Z-16 igniter squibs, and the disc at the lower left contains the 8 Z-16 whistle igniter squibs. Also in this test setup, are 5 other Z-16 squibs; 2 for floatation and stabilization bag gas generator ignition, and 3 for destruct system initiation.

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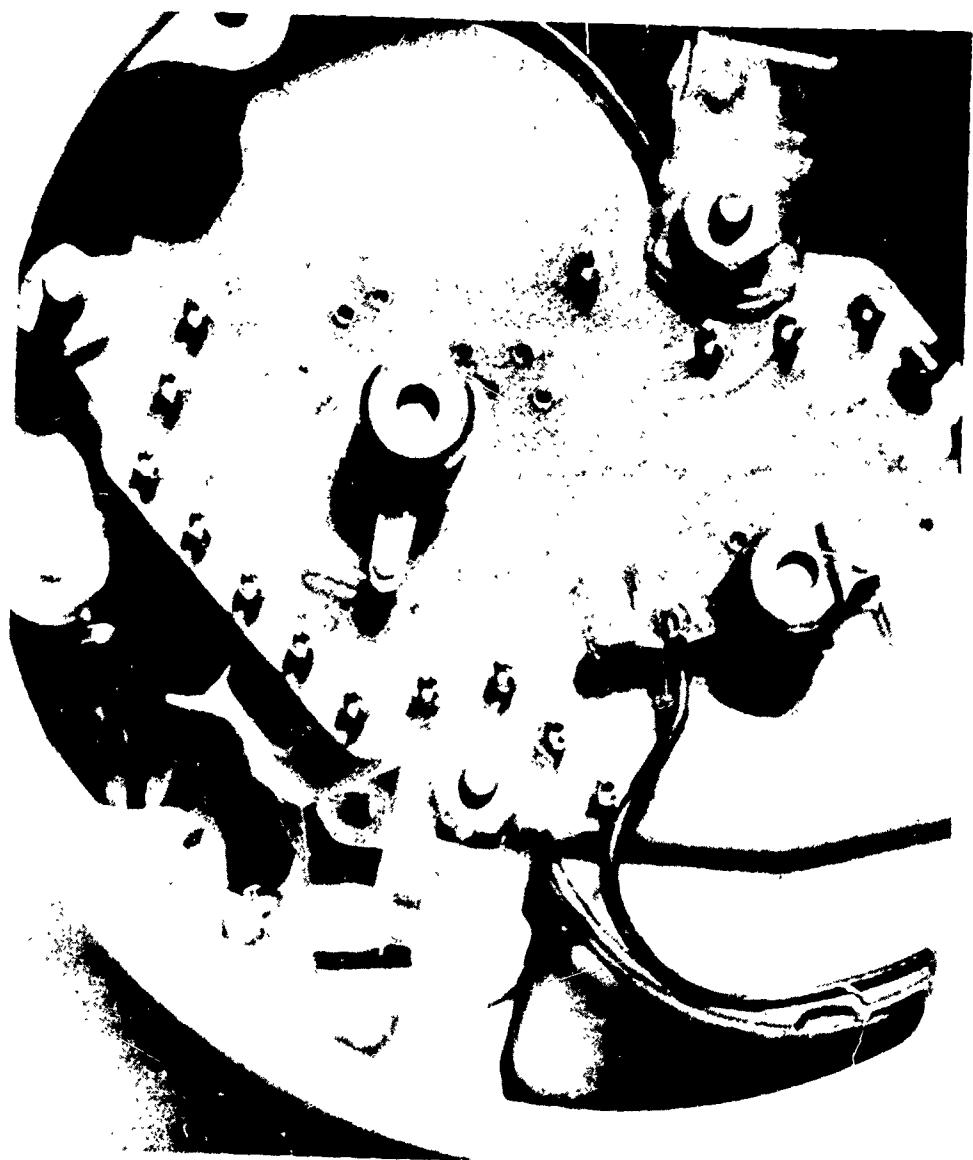


Figure 24. Electrical Delay Test Setup.

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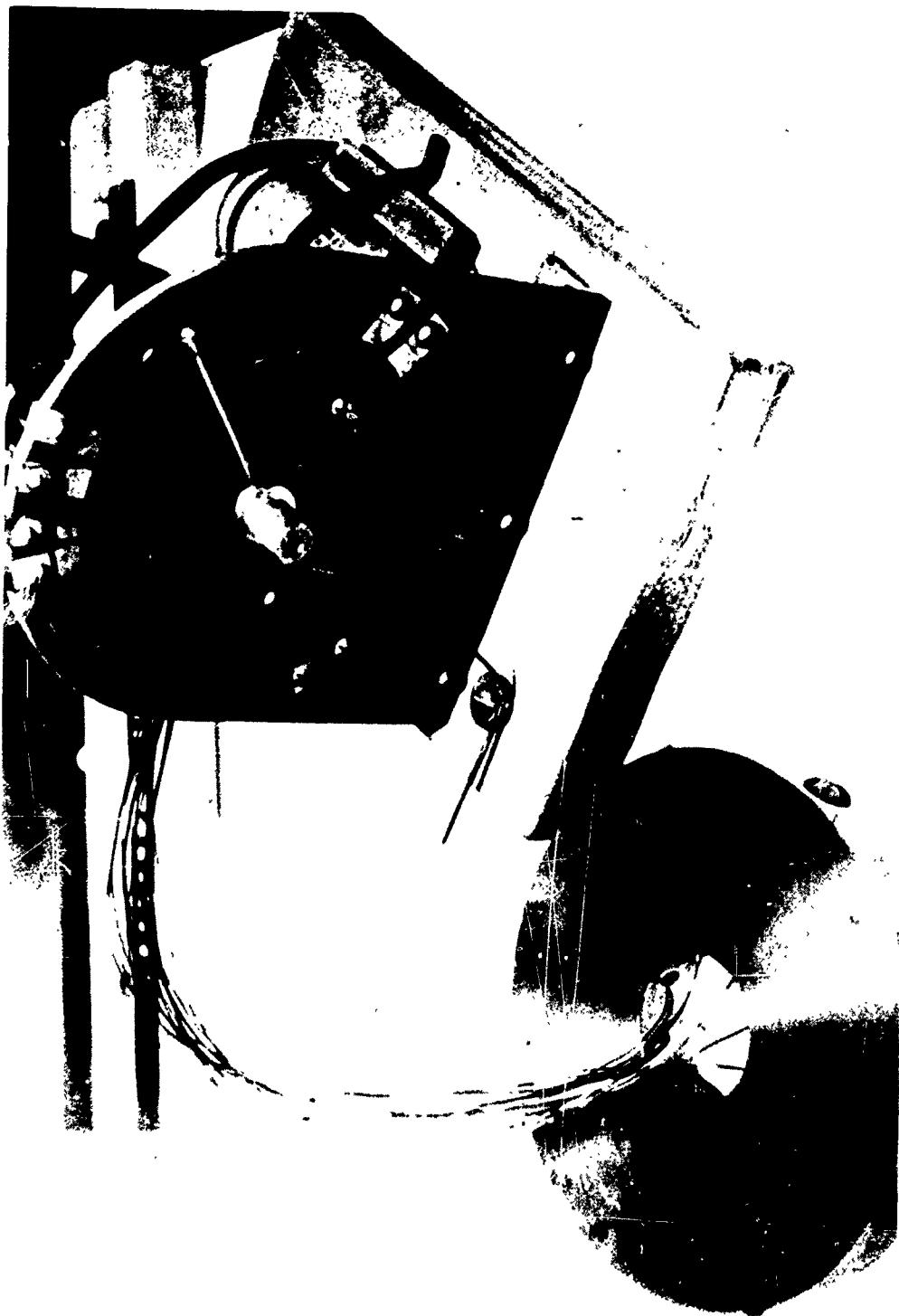


Figure 25. Electrical Delay Test Intervoltmeter.

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Figure 26. Battery Capacity Test Setup.

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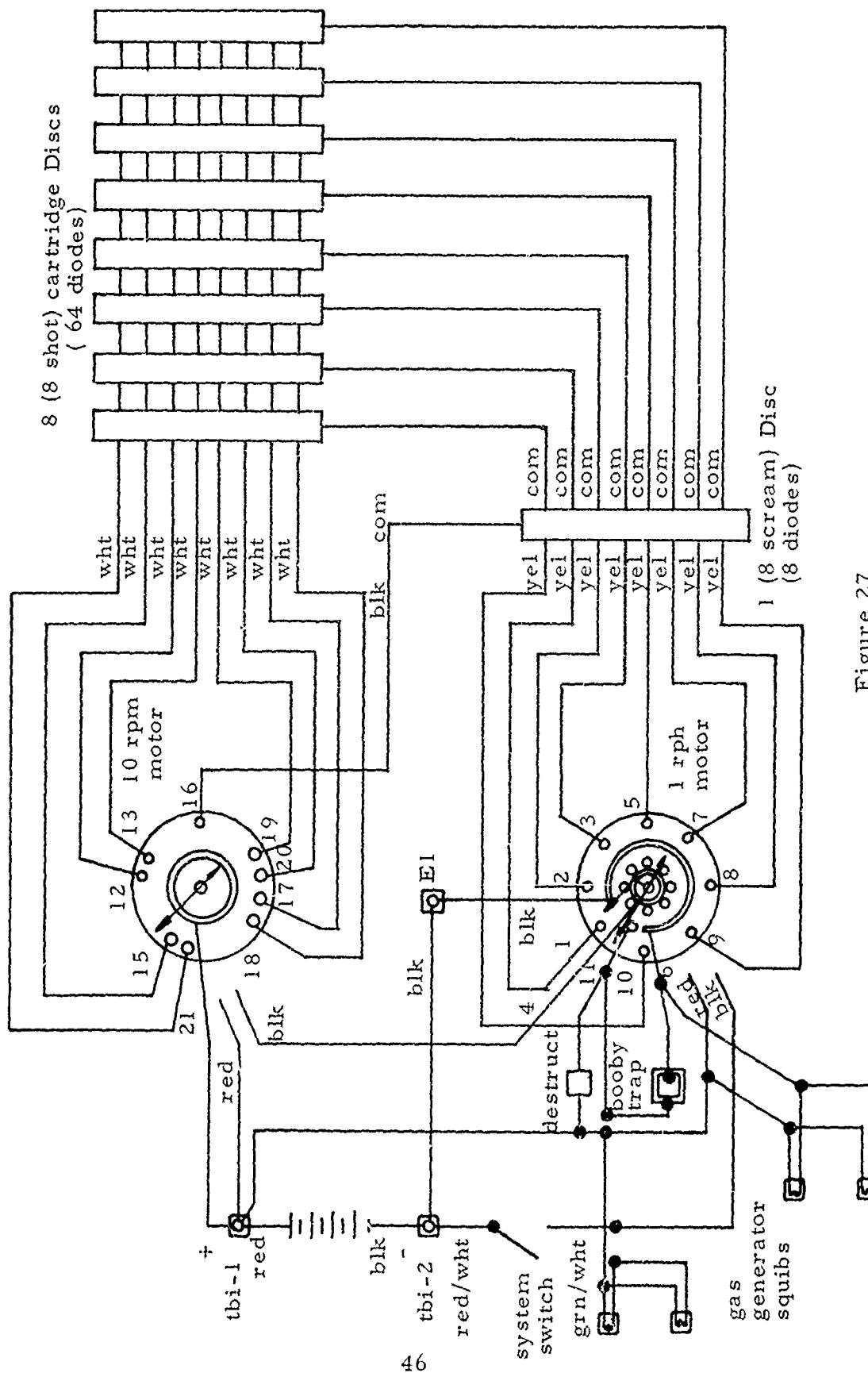
These tests were performed with 1/6 revolution per hour slow speed timers to obtain maximum current drain on the power pack. The power pack had a recovery time of approximately 30 minutes between each test, while the subsequent test unit was being wired. The fourth PHD unit tested in this series performed all functions, but the function duration increased to 7 hours, due to the decreased speed of the controller caused by the prior drain on the power pack from the three previous tests.

Figure 27 is a schematic of the PHD electrical system. The 72 blocking diodes allow only one closed circuit through the 72-point open matrix circuit of the sound generator system for each switch closure by the control system. While the prototype units are essentially hand wired, with the exception of the contact point boards on the 2 timers, this wiring would be replaced with a printed circuit on a tubular member extending through the central hole in the sound simulator container portion of the unit. The sound simulator portion would be a single molded unit that the generators are pressed into, the generators themselves would contain the diodes and pressure contacts to mate with the printed circuit. This type of assembly virtually eliminates hand wiring, is very simple, and reduces the PHD unit length by approximately 4.5 inches.

A study was made of the various possible plastic materials that could be used to mold the sound generator unit housing (discs for the prototype PHD's) since weight and cost could be reduced with the proper choice of this material, and the problem of reclaimable metal is eliminated. It was determined that nylon would meet the requirements from the standpoint of strength and moldability. Nylon also has the property of being self-extinguishing, which is necessary for the material in contact with the scream simulator grains. Figure 28 shows the molded discs used in the PHD unit. The eight holes around the circumference hold the plastic gunshot simulator units, or the scream generator gallic acid grains. The large hole in the center carries the wires from the controller to the individual sound generators, the upper floatation bag gas generator, and the timer actuation switch. Two of the four small holes, at 90 degrees from each other around the central conduit hole, are for tie rods that hold the assembled PHD unit together. The other two small holes carry the 100 grain/foot PETN destruct charge.

Because the PHD is designed for impact velocities of 65 feet/second, drop tests with the subassembly controller and sound simulator were performed. For these tests the gas generator-floatation bag assemblies were replaced with .25-inch-thick steel plates. No damage resulted in dropping the test unit from 65 feet (equivalent to a 65 ft/second impact velocity, neglecting drag) on hard ground. In all, five drops were made with one unit. Continuity checks after each drop showed 2 gunshot circuits were broken at the third drop, and 1 after the fourth drop. In both of these drops, the unit landed on its side. Subsequent functioning of the unit (after the five drops) was normal except for the 3 gunshots which did not fire. Subsequent examination of the unit (the destruct charge igniters were included in the unit but the charge itself left out) showed all three circuit failures were due to cold solder joints at the Z-16 squib/controller lead wire interface.

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Figure 27

PHD Electrical System

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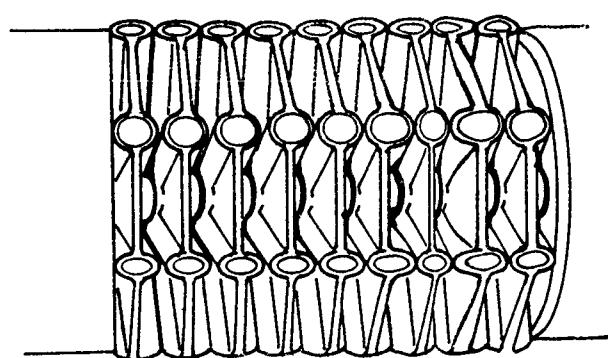


Figure 28
PHD Gun Simulator Housing Discs

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B. Orientation & Floatation System

A subsystem, or subsystems, capable of controlling impact velocity and ground orientation had to be incorporated into the PHD unit for it to be a field usable item. Impact velocity control is necessary to keep from damaging the unit beyond the point where it is operational after air delivery. Correct ground orientation insures that all sound effects will be heard.

Two other auxiliary capabilities are desirable. They are, floatation and trajectory repeatability. Floatation is closely associated with ground orientation, and insures the unit will function in watery areas. Trajectory repeatability insures the unit will land in the chosen target area.

Preliminary design analysis included studies of the components to obtain the auxiliary capabilities required, and desirable for the PHD unit. The following is a list of possible methods of achieving these support functions:

- 1) Impact Velocity Control (required)
 - o Parachutes
 - o Inflatable bladders
 - o Drag vanes & plates
- 2) Ground Orientation (required)
 - o Inflatable bladders
 - o Drag Vanes
 - o Pop-open legs
- 3) Floatation (desirable)
 - o Closed cell foam fixed shape floats
 - o Air tight container fixed shape floats
 - o Inflatable bladders
- 4) Trajectory Repeatability (desirable)
 - o Drag vanes
 - o Extendable lifting surfaces
 - o Inflatable bladders

Examination of the above shows that inflatable bladders can perform all four functions, and drag vanes three of the four functions (they do not allow floatation). All other methods considered, required a subsystem for each function.

Because of the location of the sound generators, the PHD body must be raised above the water. The only approach considered feasible by SDI, of keeping the body above the water and also fitting the SUU-13/A ejection tube, is employing an inflatable bladder on each end of the PHD body. A

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bladder on each end of the unit will also work as a ground orientation device. By inflating one bladder on ejection from the SUU-13/A, and the other after ground impact, drag stabilization for trajectory repeatability and impact velocity control can be obtained.

Hinged drag vanes that fold down along the PHD body, but open in the air stream, allow PHD installation in the SUU-13/A ejection tube. By delta hinging the vanes on a plate free to rotate about the PHD polar axis, as the vanes open they will pick up an angle of attack and rotate. Thus a drag area equivalent to the total sweep area of the vanes can be realized to drag stabilize the unit. In this manner, impact velocity can be controlled, and trajectory repeatability obtained. By locking the vanes in their outward position after ejection from the SUU-13/A, ground orientation is assured because the PHD will rest on one of the vanes, and the lower end of the body (below the control system housing).

Of the two systems, inflatable bladders vs drag vanes, the inflatable bladder could potentially perform all four functions, and is a new approach to the aerodynamic and orientation requirements. Major design and development effort went to this system, and it was incorporated in the prototype units for feasibility testing at Eglin.

Since the delta 4-hinge system has been demonstrated feasible on certain Navy Sonabouys, preliminary design calculations were made for the PHD unit, and the system held as a backup if the inflatable bladders did not prove feasible during ejection tests.

The following information presents the preliminary design analysis to establish rotor characteristics for the delta hinge vane system. The aircraft delivery velocity limits were established by Det 4 during the development program.

This analysis was based on these parameters:

- o Minimum aircraft delivery velocity \approx 150 knots
- o Maximum aircraft delivery velocity \approx 300 knots
- o Weight of PHD unit \approx 8 pounds

The preliminary analysis indicates the following rotor characteristics:

- o 4 blades at 90°
- o Blades 15" x 2" x .15" with a uniform air foil of 2.25" radius
- o Blade cant angle of 8°
- o 58 lb-in of starting torque at 150 knots
- o Terminal velocity of the unit is 52 ft/sec
- o Trim angle of attack is approximately 3°

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- o Blade loading during arresting period due to 300 knot air load is approximately 38,000 pounds

Symbols:

F_n = normal force in (lbs)

F_t = torque force in (lbs)

F = force due to gravity in (lbs)

f = force on vanes during opening due to air load in (lbs)

F_m = force due to stopping vanes during opening in (lbs)

T = starting torque or equilibrium torque (lb/in)

D = drag force in (lbs)

L = lift force in (lbs)

$\dot{\theta}$ = angular velocity in (rad/sec)

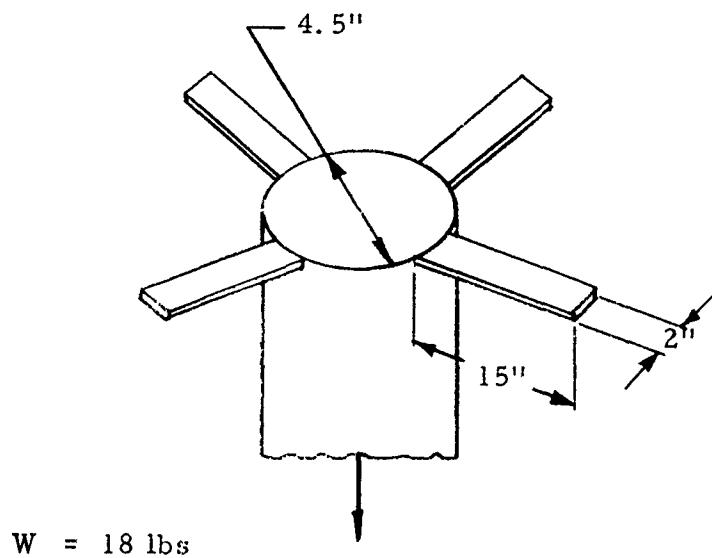
$\dot{\psi}$ = terminal velocity in (ft/sec)

α = angle of attack

ρ = air density (slugs/ft³)

V_o = effective free stream velocity (ft/sec)

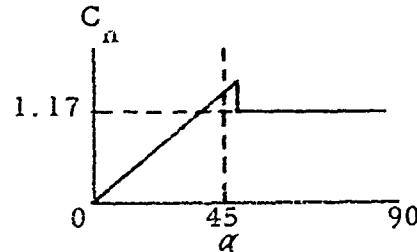
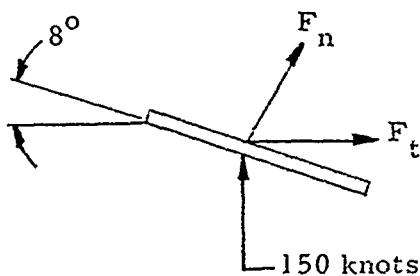
Preliminary Rotor Analysis for PHD



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1) Starting Torque (T)

Assume: Minimum delivery velocity = 150 knots



$$F_n = C_n \frac{\rho}{2} S V_o^2$$

From Hoerner @ V_o below
Mach .4

$$F_t = F_n \sin 8^\circ$$

$$= 1.17 \left(\frac{2.37 \times 10^{-3}}{2} \right) \left(\frac{2 \times 15}{144} \right) (150 \times 1.69)^2 \sin 8^\circ$$

$$F_t = \underline{\underline{2.44 \text{ lbs}}}$$

Assume: 60% efficiency due to body interference & tip losses

: 15 in-lb torque resistance (R_t) due to starting
friction & unlocking arming mechanism

: 4 vanes will be used for rotor

: the inertia (I) of the spinning mass is equal to
a steel mass 5" dia x 1" thick

: the effective torque arm $L = 10"$

$$T = .6(F_t)(L)4 = .6(2.44)(10)4$$

$$T = \underline{\underline{58 \text{ in-lbs}}}$$

2) Excess Torque (T_e) to start rotation

$$T_e = T - R_t = 58 - 15$$

$$T_e = \underline{\underline{43 \text{ in-lbs}}}$$

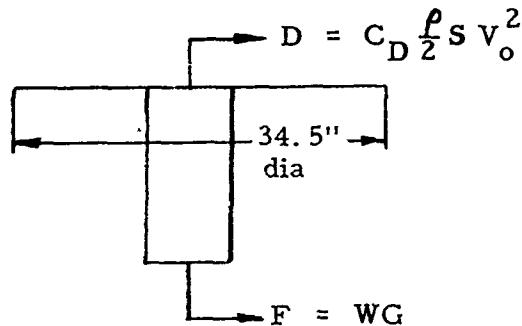
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3) Approximate Terminal Velocity $\dot{\psi}$

Assume: $W = 18$ pounds

$$C_D = .9$$



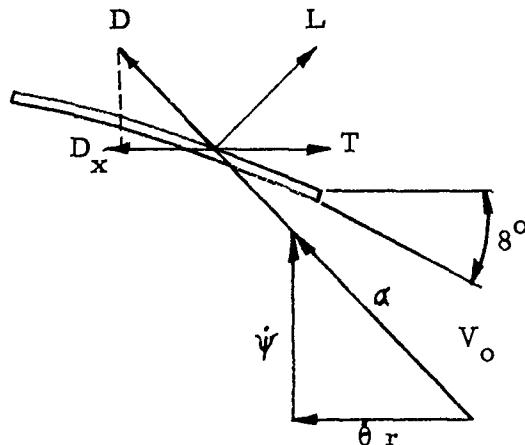
$$D = F \text{ at terminal condition}$$

$$\dot{\psi} = V_o = \left(\frac{2 W G}{C_D \rho S} \right)^{1/2} = \left(\frac{2(18)(144)}{.9(2.37 \times 10^{-3})(908)} \right)^{1/2}$$

$$\dot{\psi} = \underline{\underline{52 \text{ ft/sec}}}$$

4) Approximate Angle of Attack α and Spin Rate $\dot{\theta}$

Assume: $\alpha = 3$ degrees



Neglecting friction, the vane will auto-rotate at some velocity ($\dot{\theta}$) when the x component of the drag force (D_x) balances the torque force component (T) of the lifting force (L). Assuming $\alpha = 3^\circ$, then:

$$\tan(3^\circ + 8^\circ) = \frac{\dot{\psi}}{\dot{\theta} r}$$

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$$\dot{\theta} r = \frac{\dot{\psi}}{\tan 11} = \frac{52}{\tan 11} = 268 \text{ ft/sec}$$

and:

$$\dot{\theta} = \frac{268}{L} = \frac{268 \times 12}{12.25}$$

$$\dot{\theta} = 262 \text{ rad/sec}$$

where L = distance from polar axis to effective cp.

Now:

$$\begin{aligned} T &= L \sin 11^\circ = C_L \frac{\rho}{2} S V_o^2 \sin 11^\circ \\ &= .4 \left(\frac{2.37 \times 10^{-3}}{2 \times 144} \right) (16) \left(\frac{268}{\cos 11^\circ} \right)^2 \sin 11^\circ \end{aligned}$$

$$T = \underline{\underline{.68 \text{ lbs}}}$$

and:

$$\begin{aligned} D_x &= D \cos 11^\circ = C_D \frac{\rho}{2} S V_o^2 \cos 11^\circ \\ &= .08 \left(\frac{2.37 \times 10^{-3}}{2 \times 144} \right) (16) \left(\frac{268}{\cos 11^\circ} \right)^2 \cos 11^\circ \end{aligned}$$

$$D_x = \underline{\underline{.7 \text{ lbs}}}$$

where:

$$C_L \approx .4 \text{ at } \alpha = 3^\circ$$

$$C_D \approx .08 \text{ at } \alpha = 3^\circ$$

$$S \approx 16 \text{ in}^2 / 144 \text{ in}^2/\text{ft} = \text{effective area}$$

$$V_o = \frac{268}{\cos 11^\circ} = 273 \text{ ft/sec}$$

$$T \approx D_x \text{ at } \dot{\theta} = 262 \text{ rad/sec and } \alpha = 3^\circ$$

Check on tip velocity (V_t) which must \leq Mach 1

$$V_t = \dot{\theta} r = \frac{262 \times 17.2}{12}$$

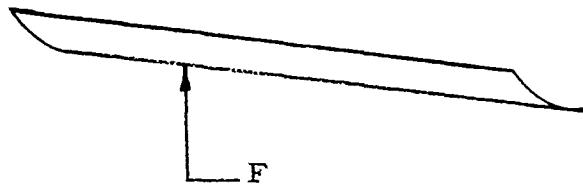
$$V_t = 376 \text{ ft/sec}$$

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Aerodynamic Loading on Vane

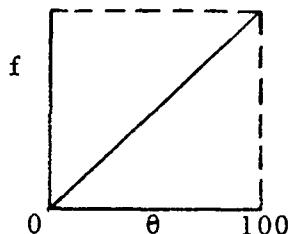
Assume: max delivery velocity = 300 knots = 507 ft/sec



Maximum possible force (f) on vane at full open position is:

$$f = C_D \frac{1}{2} \rho S V_o^2 = 1.2 \left(\frac{2.37 \times 10^{-3}}{2 \times 144} \right) (30)(507)^2$$

$$f = 76 \text{ lbs}$$



The angular acceleration during opening ($\ddot{\theta}$) is:

$$\bar{T} = I \ddot{\theta}$$

$$\ddot{\theta} = \frac{\bar{T}}{I} = \frac{76 \times 10}{2(1.09 \times 10^{-2})}$$

$$\ddot{\theta} = 3,400 \text{ rad/sec}^2$$

The mean time (\bar{t}) to open is:

$$\bar{t} = \left(\frac{2 \theta}{\ddot{\theta}} \right)^{1/2} = \frac{2 \pi 80}{180 \times 3.5 \times 10^3}$$

$$\bar{t} = .028 \text{ sec}$$

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Then, the angular velocity ($\dot{\theta}$) is:

$$\dot{\theta} = \ddot{\theta} t = 3.5 \times 10^3 (2.8 \times 10^{-2}) = 98 \text{ rad/sec}$$

$$\dot{\theta}_f = 0 \text{ rad/sec}$$

Then, if the blade is stopped, as shown in the diagram, the resulting load (F) on the blade will be the result of the air load (f) and blade inertia (I $\ddot{\theta}$)

$$\dot{\theta}_o = \dot{\theta} = 98 \text{ rad/sec}$$

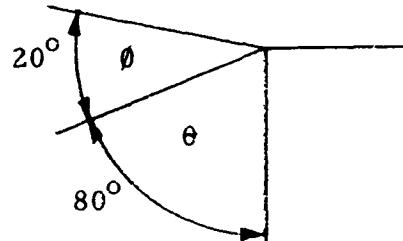
Assume stopping angle $\theta = 20^\circ$ and time to stop = .2 seconds

$$\int F_m r dt = I d\theta/dt + \int f \dot{\theta}$$

$$F_m = \frac{I \dot{\theta}}{2 t r} + f \frac{d\theta}{dt}$$

$$= \frac{1.09 \times 10^{-1} (2\pi)(20)}{2(.2)(10)(180)} + 76\left(\frac{98}{.2}\right)$$

$$F_m = \underline{\underline{3,800 \text{ lbs}}}$$



Before beginning inflation bladder and associated hardware design and development, the required inflated bladder size to float the PHD body above the water approximately 5 inches, was determined to be a 505 cubic inch bladder where approximately 22% of each bladder (one on each end of the PHD body) is submerged.

From Archimedes' principle that a body wholly, or partly immersed in a fluid is buoyed up with a force equal to the weight of the fluid displaced by the body, the volume of water that must be displaced to completely float the PHD body is:

$$V = \frac{W}{\rho} = \frac{8}{.0361}$$

$$V = 222 \text{ in}^3$$

where:

V = volume of water displaced = to the 35% of the total floatation bladder volume

W = weight of water displaced = PHD unit weight = 8 lbs

ρ = density or specific weight of fresh water = .0361 lb/in³
(salt water is heavier and therefore does not require as great a volume displacement)

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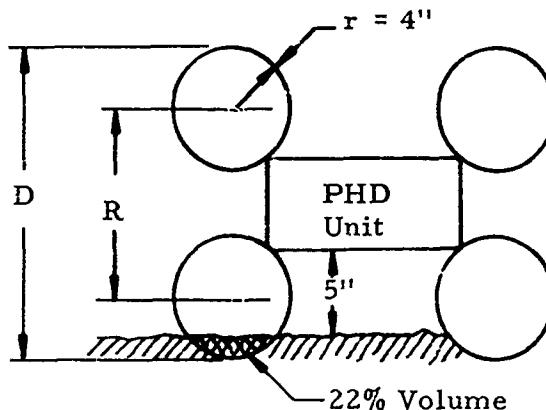
The total volume required for the inflated bladders, where they are 22% submerged, to raise the PHD body approximately 5 inches above the water, is:

$$V_B = \frac{1010}{2} = 505 \text{ in}^3$$

and the mean diameter (R) of the torus shape with a cross sectional radius of 4", is:

$$R = \frac{V_B}{\pi r^2} = \frac{505}{\pi (4)^2}$$

$$R = 10 \text{ inches}$$



The diameter of the inflated bladder (D) is:

$$D = R + 2(r) = 18 \text{ inches}$$

A bladder development program was started, and the final configuration is shown in Figure 29. It is a molded butyl elastomer unit. Unsuccessful laminated configurations are shown in Figure 30. The bladder on the left has a poor shape in that the spherical form has a low drag coefficient. The unit on the right deformed excessively when subjected to simulated 300-knot wind loads at the desired inflation pressures of 4 to 6 psi above atmospheric.

When the butyl unit shown in Figure 29 was inflated to 19 psi and subjected to the simulated wind load (as shown in Figure 31) it flattened, improving its drag coefficient slightly.

The dynamic pressure at the maximum delivery speed of 300 knots is 2.31 lb/in².

$$Q = \frac{1 \rho V^2}{2 \times 144} = \frac{1(2.46 \times 10^{-3})(520)^2}{2 \times 144}$$

$$Q = 2.31 \text{ lbs/in}^2$$

where:

$$\rho = \text{air density} = 2.46 \times 10^{-3} \text{ slug/ft}^3$$

$$V = \text{air velocity} = 520 \text{ ft/sec}$$

$$144 = \text{conversion from ft}^2 \text{ to in}^2$$

To roughly simulate this pressure, the test fixture was filled with approximately 35,000 steel balls .25 inch in diameter. While the total drag area decreased very slightly and flattened, the load caused the bladder

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Figure 29. Final Bladder Configuration.

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Figure 30. Development Bladder Configurations.

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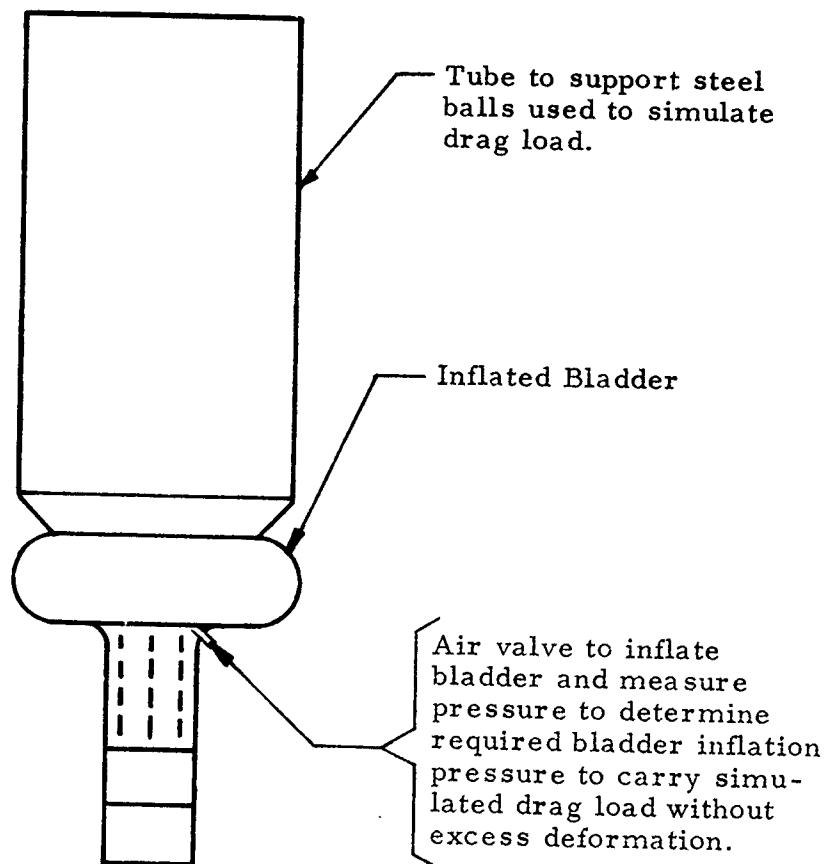


Figure 31
Wind Load Test Simulator

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to slope away from the PHD body at an angle of approximately 8 degrees.

With the change in shape of the bladder due to air load established, the approximate terminal velocity of the PHD unit, and the release altitude required to reach this velocity, were calculated to be:

- o Terminal velocity (impact velocity) 65 ft/sec
- o Freefall distance to reach terminal velocity - 1000 ft

The force (F) accelerating the PHD during freefall is that force due to gravity.

$$F = \frac{W}{g} a = W G \quad (1)$$

The retarding force (D) slowing the PHD during freefall is that force due to air drag.

$$D = C_D \frac{\rho}{2} S V^2 \quad (2)$$

Then, equating (1) and (2) and rearranging to solve for the terminal velocity:

$$V = \left(\frac{2 W G}{C_D \rho S} \right)^{1/2} = \left(\frac{2 \times 8 \times 1}{.8(2.42 \times 10^{-3})(1.97)} \right)^{1/2}$$
$$= (4,190)^{1/2}$$

$$V = 65 \text{ ft/sec}$$

where:

V = terminal velocity in ft/sec

W = weight of the PHD unit

G = unity $\frac{a}{g} = \frac{32.2}{32.2}$

C_D = subcritical flow drag coefficient estimated from "Fluid Dynamic Drag" by S. F. Hoerner, Chapt. III = .8

ρ = sea level air density = 2.42×10^{-3} slugs/ft³

S = drag area = 1.97 ft

Because of the shape of the PHD the maximum drag loading develops parallel to the polar axis, and an approximation of the freefall distance required to reach terminal velocity can be made. Because of the shape of

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the PHD, terminal velocity will be reached by, or before the time the horizontal velocity drops below the terminal velocity. In the horizontal direction, the force $m \frac{dv}{dt}$ at any time t must be equal to:

$$C_D \frac{\rho}{2} S v^2$$

where:

m = the mass of the PHD

$\frac{dv}{dt}$ = instantaneous acceleration at time t

$C_D \frac{\rho}{2} S v^2$ = aerodynamic loading on the PHD

Then the horizontal velocity component can be determined as follows:

$$m \frac{dv}{dt} = C_D \frac{\rho}{2} S v^2$$

$$m v^{-2} dv = C_D \frac{\rho}{2} S dt$$

$$\frac{1}{V} \left[\frac{t}{V} \right] = \frac{C_D \frac{\rho}{2} S}{2 m} t$$

$$V_t = \frac{\frac{1}{C_D \rho S} t}{\frac{1}{V_0} + \frac{C_D \rho S}{2 m}}$$

and solving for V_t at increments of $t = 1$ sec

<u>t - sec</u>	<u>V_t - ft/sec</u>
1	370
2	264
3	188
4	134
5	95
6	67
7	48

when C_D is varied from .8 to .4 and S varied from 1.97 to 1.38 in the above equation as the polar axis of the PHD changed from the horizontal to the vertical with increasing time(t).

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Then the approximate vertical drop distance during free-fall before terminal velocity is reached, is:

$$y = \frac{1}{2} g(t_i + t_d)^2 = \frac{32.2}{2} (8)^2$$

$$y = 1000 \text{ ft}$$

where:

y = vertical distance

g = gravitational constant = 32.2 ft/sec²

t_i = time required for bladder inflation = 1 sec

t_d = time required for drag retardation = 7 sec

The inflatable bladder assembly is shown in Figure 29 with the gas generator coaxially located in the center of the bladder housing. The gas generator grain is cast from the following constituents:

Ammonium Perchlorate	70%
Hexamethylenetetramine	25%
Polyisobutylene	5%

This material was chosen because it produces a large amount of gas per unit weight of solid grain material, and eliminates the requirement for extensive baffling to reduce gas temperature for bladder protection.

The grain is .75" in diameter by 2.625" long and is regressive burning over its entire external surface. The burning rate is .375 in/sec at 600 psi, and ignition is achieved by coating one end and the O.D. with 20 grains of 80-20 boron barium chromate with a Z-16 squib in contact with the coated end. Figure 32 shows a typical bladder inflation test unit prior to testing, and Figure 33 shows the unit after test.

The gases from the generator are passed over the baffle and through the fine wire mesh, shown in Figure 34, to protect the bladder. Immediately after inflation, the bladder pressure is 22.8 psia, which reduces to 19.2 psia upon cooling to 70 degrees.

Upon ejection from the SUU-13/A the pressure sensitive switch (located in the upper bladder housing) closes the electrical circuit to the Z-16 squib in the upper bladder gas generator completely inflating this bladder in 1 second. The lower bladder is inflated approximately 1 minute after PHD ejection from the SUU-13/A. It is initiated by the controller which is started by the pressure sensitive switch that initiates the upper bladder gas generator.

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Figure 32. Bladder Test Unit Before Test.

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Figure 33. Bladder Test Unit After Test.

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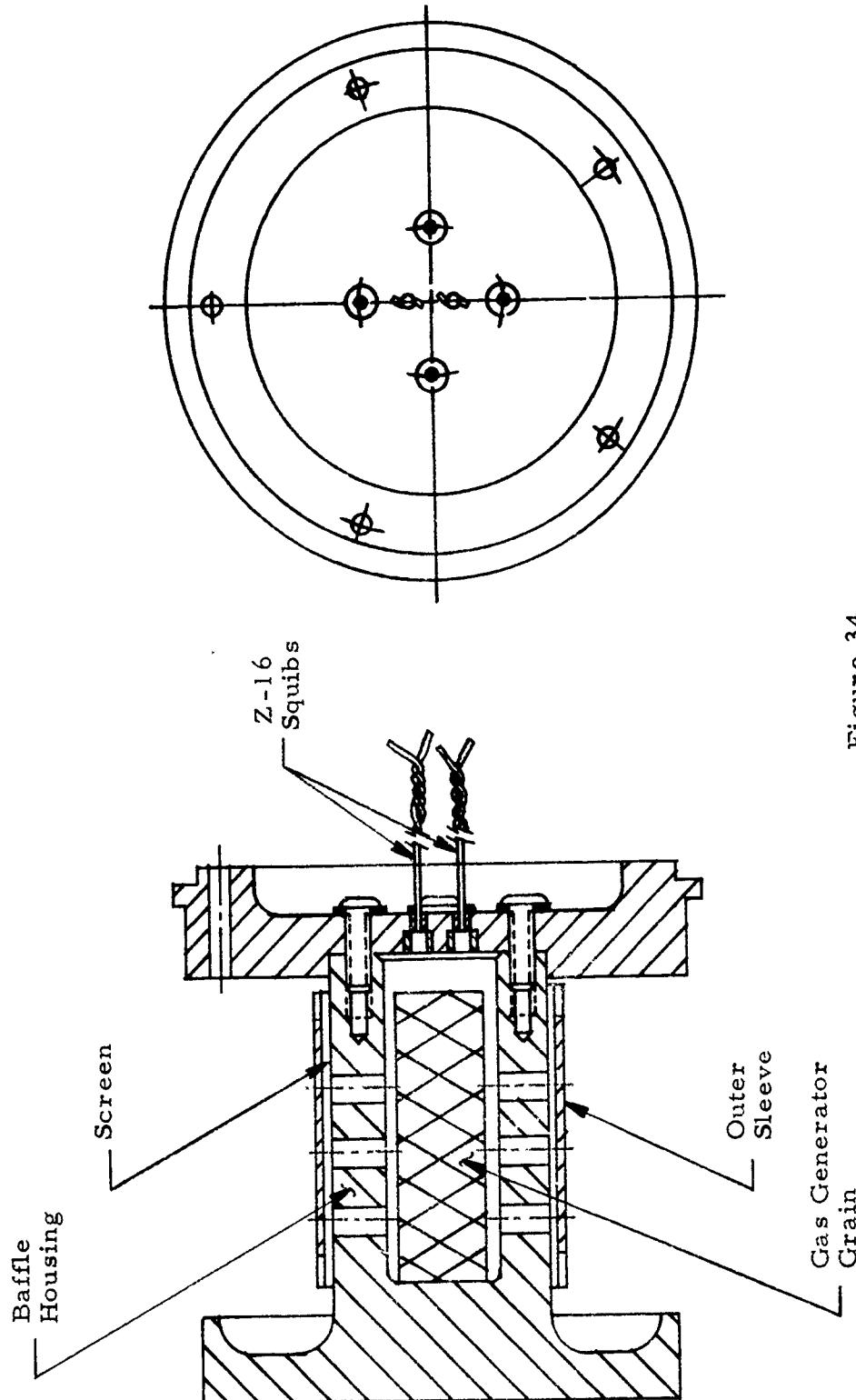


Figure 34

Gas Generator Components

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C. Destruct System

The PHD destruct system contains .1 lbs of PETN. The explosive is located in the unit as shown in Figure 35. The 3 separate lengths, totalling 42 inches, have an explosive weight of 100 grains per foot. Each length is fuzed separately with a Z-16 squib for ease of assembly and redundancy.

For normal destruction, referring to Figure 27, when the rotary contact of the 1 rph motor reaches point 11 the destruct circuit is closed to the 3 Z-16 squibs, and the unit destroyed. Normal destruction takes place after all other functions, because the 1 rph motor rotates clockwise and begins operation between point 11 and 1. The antitamper circuit bypasses the usual destruct circuit and functions upon closure of a G switch in the control circuit. Again, referring to Figure 27, the continuous contact strip on the contact board of the 1 rph motor completes a circuit to the negative side of the first cell in the power pack through the rotary contact, 1 minute after the PHD is delivered from the SUU-13/A.

From the continuous contact strip through the destruct squibs to the positive side of the power pack, the circuit is interrupted by the booby trap G switch.

Tests were made with an accelerometer to measure the acceleration on the PHD caused by the gunshot simulators and the scream simulators. The test setup is shown in Figures 36 & 37. The readings from these tests are shown in Table VI.

Table VI
G Loads on PHD from Simulator Functioning

Test No.	Type	Polar Axis	Transverse Axis
1	Gunshot	0	60.0 G's
2	Gunshot	0	58.0 G's
3	Gunshot	0	59.0 G's
4	Gunshot	0	60.0 G's
5	Gunshot	0	59.0 G's
6	Scream	0	0.4 G's
7	Scream	0	0.5 G's
8	Scream	0	0.5 G's
9	Scream	0	0.3 G's
10	Scream	0	0.4 G's

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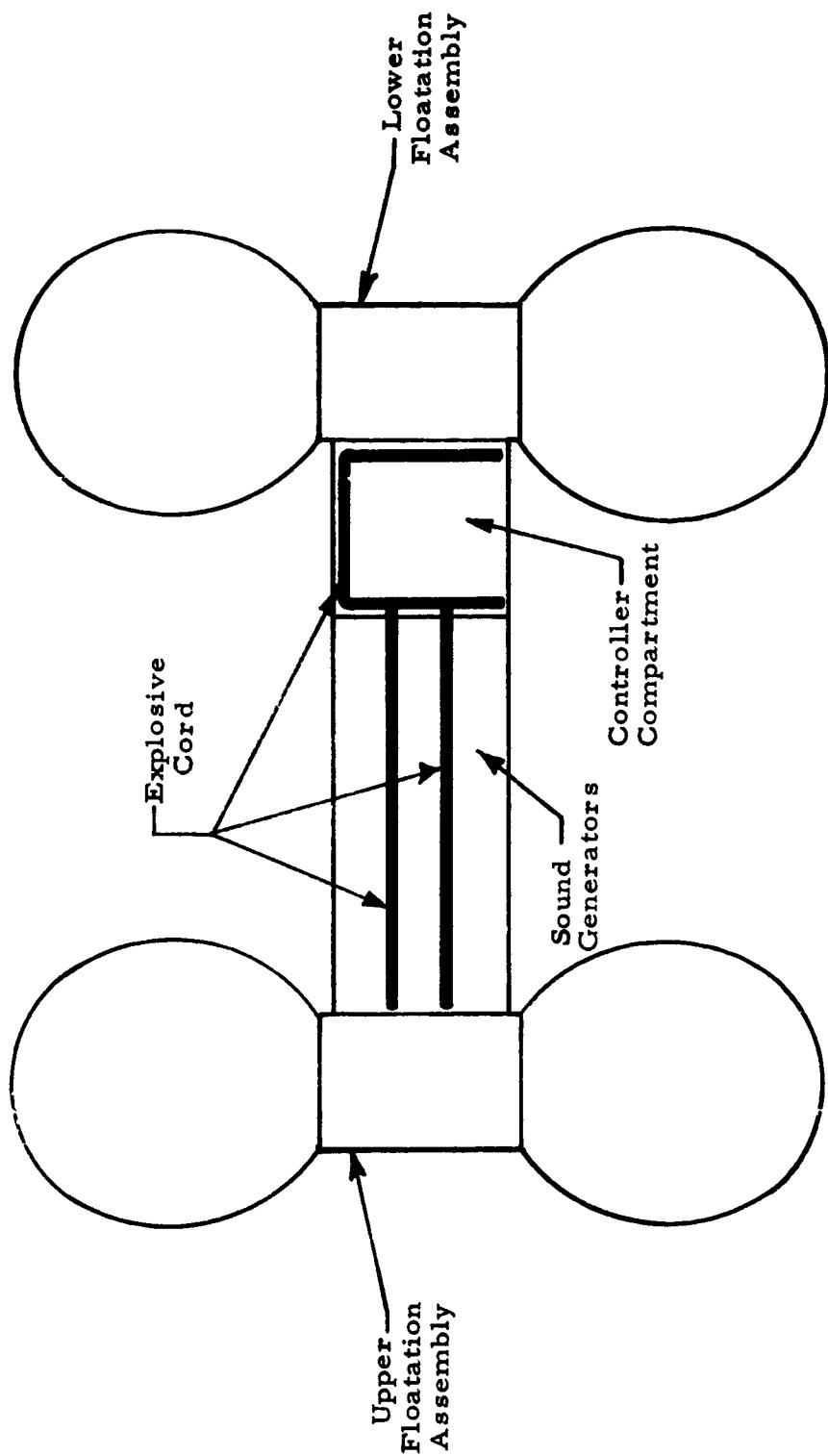


Figure 35
Destruct System Location in PHD

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Figure 36. G Load Test.

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Figure 37. G Load Test.

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A G switch located on the polar axis of the PHD is feasible for the field unit because it is only subjected to the centrifugal force developed by the torque in the transverse plane. This switch has a sensitivity of .44 G's, and fires the destruct system when a force along the polar axis of 2.66 lbs is realized. However, a 9 G unit was used in the prototypes because it allowed demonstration of the principle, while still retaining a large factor of safety during testing. The sensitivity of the G switch is calculated as follows:

$$\begin{aligned} F &= W G \\ &= 4(60) = 240 \text{ lbs (for gunshots)} \\ &= 4(.5) = 2 \text{ lbs (for scream)} \end{aligned}$$

where:

$$\begin{aligned} F &= \text{force developed} \\ W &= \text{weight of test fixture} = 4 \text{ lbs} \\ G &= \text{maximum level acceleration coefficient} \\ &\quad \text{measured during tests} \end{aligned}$$

Then the impulse developed is:

$$\begin{aligned} A &= F dt \\ &= 240(.01) = 2.4 \text{ lb-sec (for gunshot)} \\ &= 2(3) = 6 \text{ lb-sec (for scream)} \end{aligned}$$

where:

$$\begin{aligned} A &= \text{impulse} \\ dt &= \text{duration of impulse} = 10 \text{ ms for gunshots} \\ &\quad 3 \text{ sec for scream} \end{aligned}$$

To be conservative, the peak force is used over the entire duration.

Since the impulse from the scream generators is the larger of the two, all the scream generators were located in one disc and the disc placed at the bottom end of the stack (next to the control system) close to the cg of the PHD. Then the maximum torque developing impulse is caused by the gunshot simulators located in the disc most distant from the cg at the top of the stack. Due to this torque, the angular velocity of the PHD, neglecting friction, is 13.1 rad/sec.

$$\dot{\theta} = \frac{A R}{I} = \frac{2.4 \times .66}{.121}$$

$$\dot{\theta} = 13.1 \text{ rad/sec}$$

where:

$$\begin{aligned} \dot{\theta} &= \text{angular velocity} \\ R &= \text{torque arm} = .66 \text{ ft} \\ I &= \text{transverse moment of inertia} = .121 \text{ slug ft}^2 \end{aligned}$$

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Then the acceleration coefficient along the polar axis of the PHD unit is:

$$G = \frac{a_n}{g} = \frac{14.3}{32.2}$$

$$G = .444$$

where:

$$a_n = \text{normal acceleration due to centrifugal force}$$
$$= r \theta^2 = 14.3 \text{ ft/sec}^2$$

$$r = \text{length from the cg of the PHD to the cg of}$$
$$\text{the G switch} = \text{to } 1/2 \text{ ft}$$

and the force along the polar axis required to fire the destruct system is:

$$F_p = W G = 6(.444) = 2.66 \text{ lbs}$$

This force would be developed from impact, or if the PHD unit is rotated from the horizontal 63.7 degrees:

$$\angle = \cos^{-1} \frac{2.66}{6} = 63.7^\circ$$

Thus, the booby trap is a compromise that is fairly sensitive to movement or impact, but can resist ambient force due to wind or wave action, and is insensitive enough to allow a wide variation in operational attitude due to implacement in trees, bushes, on irregular ground, or rough water.

Figure 38 shows a PHD ready for destruct testing and Figure 39 shows the same unit after the destruct charge was fired. The entire sound generator system is powdered, thus eliminating any possible determination of the units purpose from post examination. The control unit housing is fragmented and all components damaged beyond re-use, particularly the plastic housed timing motors. The floatation and orientation bags are intact but punctured and torn, the gas generator and floatation bag housing survives with minimum damage.

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Figure 38. Destruct Test Unit Before Test.

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Figure 39. Destruct Test Unit After Test.

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VI

EGLIN TESTS

During the third month of the program, 2 gunshot discs containing 8 simulators each were sent to Eglin for evaluation of the final gunshot simulator configuration and the proposed 4-2-2 firing sequence. Both the gunshot output and sequencing were considered satisfactory.

During the fourth month of the program, a tape of the sound generation studies was sent to Eglin. This tape included real sounds that were analyzed as discussed in Section II of this report, and gunshot and scream simulator outputs. Of principle interest on this tape were the scream simulator outputs, and while their fidelity was considered marginal, the decision was made to include the best in the prototype PHD units.

During the final month of the program, 5 PHD prototype units were sent to Eglin. These units were made up as follows:

- o One PHD for demonstration purpose. This unit could be disassembled, was completely wired, and contained an operational control system. It contained no simulator pyrotechnics, gas generator propellant, or destruct explosives.
- o Two PHD's for air delivery by hand release from light cargo aircraft. For safety, these units did not contain the explosive destruct charge, and the proposed pressure actuation switch was replaced with a lanyard operated shear pin arming device.
- o Two PHD's for system testing, to be hand implaced and activated remotely with a lanyard. Just prior to shipment it was decided that the G switches in the booby trap should be left out, for added safety. This decision was made because only limited testing of the booby trap system had been made, due to difficulty in obtaining suitable switches.

The open matrix condition in the simulator circuit was not discovered until after shipment of the prototypes to Eglin. Four additional control units incorporating the diode fix were prepared to replace those in the live PHD's scheduled for Eglin testing. The decision was made to test the two units originally scheduled for air delivery by ground implacement to demonstrate functional operation, including bladder inflation and sound simulation, and use the other 2 units for destruct tests only. Just prior to testing, the control systems were changed at Eglin. The units were then tested, and the tests witnessed by a group of approximately 25 Air Force personnel and the PHD program engineer from Special Devices, Incorporated. The units performed all functions, from bladder inflation, through sound simulation, to destruct system operation. However, one PHD developed an estimated 6 to 10 hour delay during the sound generation cycle. When this unit quit functioning, it was left in the field for the

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remainder of the night. Examination the following morning showed the unit had finished functioning some time during the night. The probable reason for this delay in operation was a bad connection between the power pack and the function timer.

The flash from the gunshot simulators was considered too bright because the excessive light output made the PHD easy to locate during sound simulation. This is not a serious problem because the pyrotechnic mix can be reformulated, reducing the flash producing materials without adversely affecting the sound output.

The scream generators were judged unacceptable because of their poor fidelity. Their sound output was too close to that of a pure whistle. The whistle sound associated with gun shots did nothing to enhance the overall effect caused by the PHD. Based on the studies performed during the sound generation portion of the program, there appears to be no way to make a pyrotechnic scream simulator with satisfactory characteristics for the PHD unit.

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VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- o By reducing the output level for human sounds to 90 db at 2 feet, a harassment device capable of meeting all requirements in a single unit, is technically feasible.
- o The incorporation of a large number of, and different types of sound simulators in a single unit results in a level of complexity that is not economically desirable.
- o Pyrotechnic sound simulation is only applicable for gunshots and whistles. The more complex human and animal sounds should be reproduced with a mechanical phonograph.
- o Sound pressure level output of 80 db at 100 feet is not needed for speech simulation. It results in unreasonably loud voices near the generator, and imposes severe limitations on the potential of the harassment device concept, because it eliminates the use of a simple mechanical phonograph system.
- o Harassment device concept has merit, but simplified hardware must be developed before its potential can be determined.
- o Hardware simplification can be achieved without adversely affecting the PHD concept by reducing the number of functions an individual unit must perform, reducing the operational duration, and limiting the number and type of simulator. These steps will allow simplification of the overall unit, and associated timing and delay components.

Recommendations

- o Continue harassment device hardware studies, but prior to establishing requirements, perform a design definition effort based on the results of this program, to fix minimum requirements that are not directly related to sound generation.
- o Limit individual harassment units to a single sound generation function and a destruct system. Possibilities include a pyrotechnic gunshot unit, a phonograph human and animal sound unit, and a pyrotechnic whistle unit.

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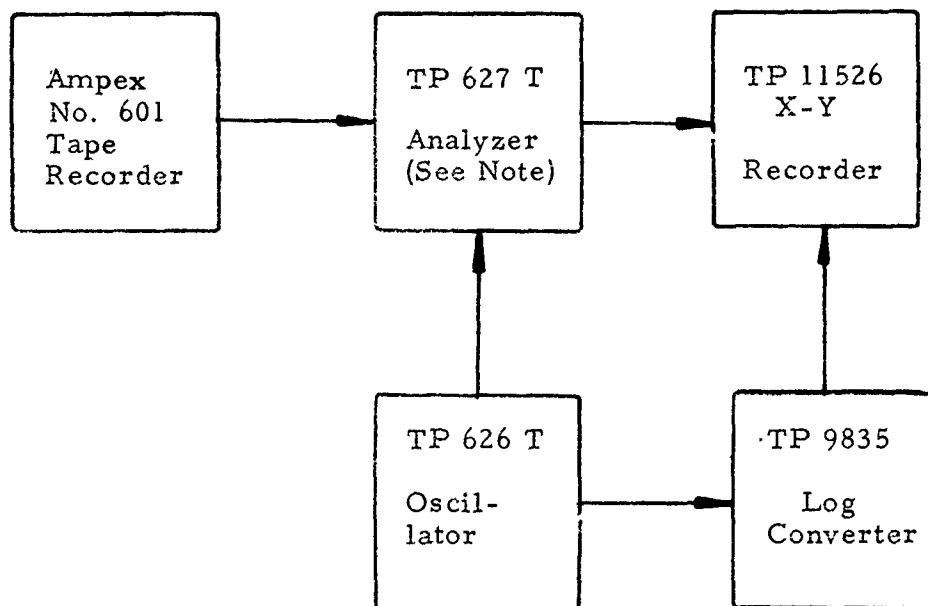
- o Make the units compatible with a single internal dispenser that can be reloaded in-flight with any mix of units desired.
- o With the exception of the human and animal sound unit, use pyrotechnic delays between functioning of sound generators, and delay the unit function with a simple fuze. For example, a suitable low cost delay fuze is a frangible acid vial, and iron wire. When the unit is ejected, the primary firing pin is cocked by the iron wire, which breaks the acid vial. The acid reacts with the iron wire, releasing the firing pin, igniting the first sound generator, with subsequent generators being fired through pyrotechnic delays at a rate of approximately 500 rounds/minute. The last element in the series of generators and delays would be the destruct charge. Initial delay times from 1 to 6 hours can be achieved by varying the acid concentration.
- o If a whistle unit is considered include progressive, regressive, and neutral burning gas generator grains so the sound output will, in some cases, give the effect of coming toward the listener, going away from the listener, or remaining at a fixed distance from the listener.
- o Design the phonograph unit for "on" and "off" operation over a 6-hour period. Because of the nature of the mechanism in this unit, on-off operation does not significantly complicate the design. Consider the possibility of making a field recording unit to put the most appropriate sounds on the records for the specific condition and geographic location.
- o By limiting the units to a single sound generation function, and a destruct system, they can be kept light, small, and rugged even when made of plastic. Therefore, the units can be designed to withstand ground impact without the aid of terminal velocity limiting devices (they can be designed with a low ballistic coefficient). Also eliminate special ground orientation devices, because the reaction from the pyrotechnic generators will result in self-orientation of the light units. This approach will greatly reduce the complexity and cost of the units as compared to the multi-purpose feasibility unit developed during this program.
- o Limit the individual unit size to a maximum volume of approximately 60 cubic inches (a cube 4" x 4" x 4", or cylinder 4" in diameter by 4" long). This volume will allow room for approximately 20 gurshot simulators or 4 whistles each, with a six second duration or 100 seconds of recorded material.

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APPENDIX I

Schematic of instrumentation used in establishing frequency versus db drop curves.



NOTE:

Equipped with

TP 218H 2 cps filter
TP 218G 10 cps filter
TP 218C 20 cps filter
TP 218E 200 cps filter

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APPENDIX II

INSTRUCTIONS FOR FUNCTIONING PHD UNITS SERIAL NOS. 2, 3, 4, 5

1. General Information

Each unit is equipped with:

- a. Sixty-four 38 caliber blank cartridges
- b. Eight pyrotechnic whistles
- c. Two gas generators
- d. Five mercury batteries
- e. Two electric intervalometers
- f. Three pieces (total of 2 feet) of 100 grain primacord
- g. Unit No. 2 is also equipped with an inertial switch to fire the primacord destruct charge if the unit is shocked above 9 g's.

2. Operation

- a. Place the unit in a safe location where the fragments will do no damage when the destruct unit functions as the last operation. Always assume that the destruct charge may fire prematurely.
- b. Tie a lanyard several feet long through hole in the switch actuating member.
- c. Locate two wires protruding from the outside surface of the unit. These emerge from the motor housing about midway (end-to-end) of the unit and are provided as an added safety device. In order to determine if the actuating switch is still in the "off" condition a d. c. voltmeter with a range of 0 to 10 volts can be connected to these two wires. If no reading is obtained, the switch is in the "off" (normal) position. Connect the ends of the two wires and insulate the connection.
- d. Remove safety pin/ The shear pin will still prevent the switch actuating member from being inadvertently withdrawn.
- e. Pull the lanyard with sufficient force (about 20 pounds) to shear the pin and withdraw the switch actuating member. The floatation bag nearest the switch should immediately inflate. The same switch actuation will also start the slow speed intervalometer. In approximately 2 to 4 minutes this intervalometer will reach its first program point and cause the second floatation bag to be inflated.
- f. The gun fire discs and whistles will function at intervals of 6 to 8 minutes after actuation of the starting switch.

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- g. It is not recommended that a functioning unit be approached after it is once started. However, the unit can be stopped and rendered safe by cutting the wire loop that was formed by making the connection described in paragraph 2c above.

3. Operation in Water

To function Serial Numbers 2, 3, 4 or 5 in water, the following should also be observed in advance of the operation:

- a. Be sure the ends of the spaghetti tubing covering the wires, mentioned in paragraph 2c, are made water tight to prevent water from entering the space between the tubing and the wire.
- b. Be sure the joint between the tubing and case is sealed inside the unit.

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APPENDIX III

DRAWING LIST OF PHD UNIT COMPONENTS

<u>Drawing No.</u>	<u>Description</u>
101812	PHD Assembly
101729	Floatation Device
	Screw, Button Hd. Socket, #6-32 x 1/2 Lg.
	Screw, Pan Hd. Cross Recessed, P/N NT352R0632A16, Abscoa Industries
	Lock-O-Seal, P/N 800-015-6, Parker Seal Co.
	Silastic RTV-732, Dow Corning Corp.
	Solder, SN60 per QQ-S-571
	Band, Cres, 1/4 Wide, P/N 202, Band-It Co.
	Buckle, Cres, 1/4 Wide, P/N 252, Band-It Co.
	Aluminum Foil
101805	Gas Generator Assembly
101759	Body
101760	End Plate
101761	Baffle
101085	Squib, Type Z-16
101818	Screen
500342	Prime
	Screw, Button Hd. Soc. 4-40 x 5/8 Lg.
	Lock-O-Seal, P/N 800-015-4, Parker Seal Co.
	Resiweld #7004, H. B. Fuller & Co.
101813	Pellet - Cored
500338	Fosite
101814	Pellet - Stepped Core
500338	Fosite
101800	Power & Switching Assembly
101690	Printed Circuit Board
101715	Housing
101721-1	Bracket
101721-2	Bracket

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<u>Drawing No.</u>	<u>Description</u>
101722	Spacer
101732	Clamp Bonded Sandwich Mounting P/N J-6984-22, Lord Mfg., Co.
	Battery, Mercury, P/N RM 1450R, Mallory Battery Co.
	Motor, 6 VDC, 1 RPH, P/N 2AAB2A 252Y0277A-AAX R, Giannini Controls Corp., Cramer Div.
	Motor, 6 VDC 10 RPM, P/N 2AAB2A 252Y0277A-AAP R, Giannini Controls Corp., Cramer Div.
	Screw, Button Hd. Soc., 6-32 x 3/4 Lg.
	Screw, Flh Soc., 6-32 x 1/2 Lg.
	Screw, Flh Slot, 8-32 x 9/16 Lg.
	Nut, Hex, 6-32
	Nut, Hex, 8-32
	Wire Strd, 24 AWG per MIL-W-16878, Type E, Black
	Solder, SN60 per QQ-S-571
	Insulation, Sheet .015 Thk.
	Insulation Tape, Elec, Plastic
	Wire, Strd, 24 AWG per MIL-W-16878, Type E, Red
	Sofdet 100-12, De La Mare Engrg. Co.
	Silastic RTV 732, Dow Corning Corp.
	Cable Clamp, Plastic, 3/16 ID
	Terminal Strip, 2 Lug, P/N 52, Cinch Mfg. Co.
	Terminal Strip, 1 Lug
101716	Rotary Contact Assembly
101710	Arm
101713	Bushing
101714	Contact Eyelet, 3/64 Barrel OD x 3/32 Lg. Solder, SN60 per QQ-S-571

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<u>Drawing No.</u>	<u>Description</u>
101717	Rotary Contact Assembly
101710	Arm
101713	Bushing
101714	Contact
	Eyelet, 3/64 Barrel OD x 3/32 Lg.
	Solder, SN60 per QQ-S-571
101808	Gas Generator & Disc Assembly
101718	Cover
101750	Gasket
MS35489-4	Grommet
	Sofdet 100-6, De La Mare Engrg. Co.
	Stud, Alum., 6-1/4 Lg, 10-32 x 1/2 Both Ends
	Lock-O-Seal, P/N 800-015-10, Parker Seal Co.
	Nut, Allen, 10-32, Allen Mfg. Co.
	Nut, Hex, 10-32
	Wire, Strd, 22 AWG per MIL-W-16878, Type E, White
	Solder, SN60 per QQ-S-571
	Resiweld #7004, H. B. Fuller Co.
	Wire, Strd, 24 AWG per MIL-W-16878, Type E, Yellow
	Silastic RTV 732, Dow Corning Corp.
	Wire, Strd, 24 AWG per MIL-W-16878, Type E, Black
	Cable Clamp, Plastic, 3/16 ID
10804 Rev. "A"	Gas Generator Assembly
101719	Guide
101720	Piston
101757	Body
101758	End Plate
101761	Baffle
101819	Shear Pin
101085	Squib, Type Z-16
101818	Screen
500342	Prime

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<u>Drawing No.</u>	<u>Description</u>
AN 415-2	Lock Pin
MS24547-1	Switch, Sub-subminiature (ISXI-T, Micro Switch)
	Lock-O-Seal, P/N 800-015-4
	Screw, Pan Hd. Slot, 2-56 x 1/2 Lg.
	Screw, Flh. Cap, 6-32 x 1/2 Lg.
	Screw, Button Hd. Cap, 4-40 x 5/8 Lg.
	Resiweld, #7004, H. G. Fuller & Co.
101813	Pellet - Cored
500338	Fosite
101814	Pellet - Stepped Core
500338	Fosite
101806	Biank Cartridge Disc Assembly
101697	Disc
101085	Squib, Type Z-16
500279	Hi-Grade Flash
	.38 Caliber Spl. Plastic Case, Wallmax Inc.
	Wire, 24 AWG Heavy Formvar per MIL-W-583, Type T2
	Solder, SN60 per QQ-S-571
	Resiweld #7004, H. G. Fuller & Co.
	Sleeving, Alphlex P/N PVC-105-20, Alpha Wire Corp.
	RTV-102, White, General Electric Co.
101807	Whistle Disc Assembly
101697	Disc
101085	Squib, type Z-16
500341	Whistle Mix
	Wire, 24 AWG Heavy Formvar per MIL-W-583. Type T2
	Solder, SN60 per QQ-S-571
	Resiweld #7004, H. B. Fuller & Co.
	Drive Rivet, Alum, P/N 38-104-02-13, South Co.
	Caplug No. 3, Protective Closures Co., Inc.

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<u>Drawing No.</u>	<u>Description</u>
	Sleeving, Alphlex P/N PVC-105-20, Alpha Wire Corp.
101696	Wiring Diagram - PHD

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